Assisi, June 20-24, 2005

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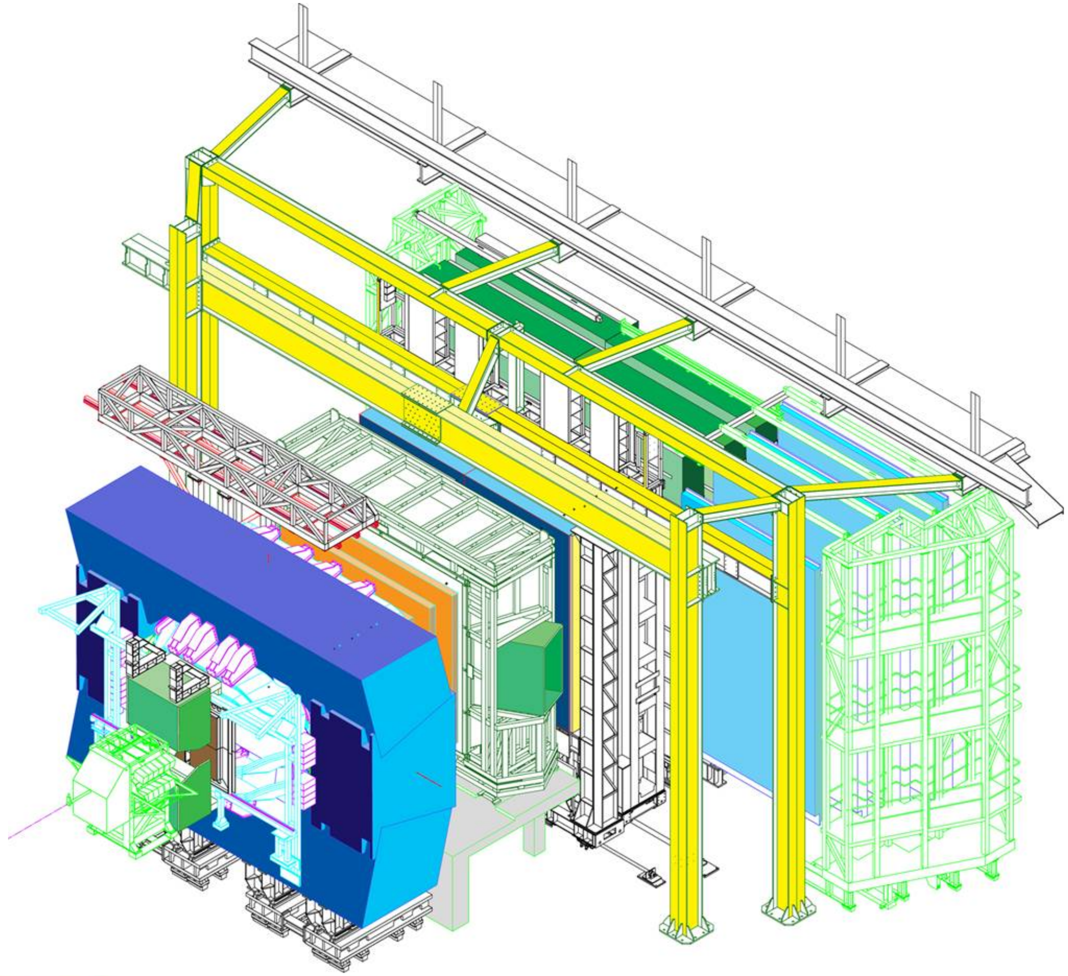
CERN and ITEP,Moscow

On behalf of the LHCb collaboration

The LHCb experiment:
Status and expected physics performance

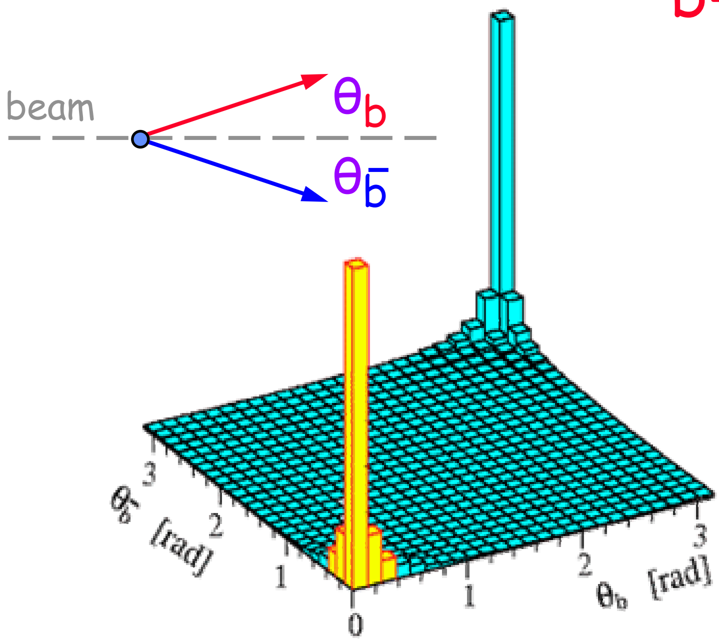


Introduction

- LHCb is a dedicated experiment to study CP violation and other rare phenomena in B meson decays (and also c,τ,jets,...):
  - Precision measurement of CKM parameters;
  - Test of Standard Model predictions / search for new physics
- Expect ~10^{12} b-hadrons / year
- All b-species are produced: B_u (~40%), B_d (~40%), B_s (~10%), B_c (~0.1%), Λ_b (~10%), ... , Excited states, ...
- B_u, B_d are being explored in great detail (thanks to B-factories)

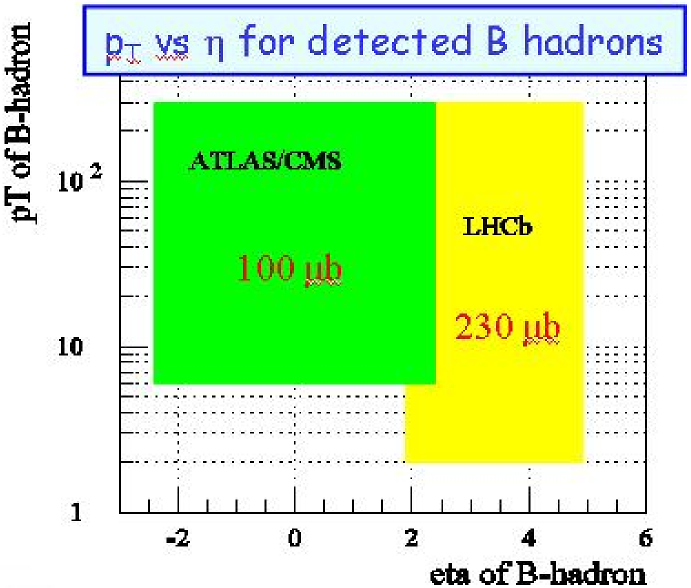
  => Improve statistics (other sources of systematics)
- B_s time resolved studies (not accessible at B-factories)

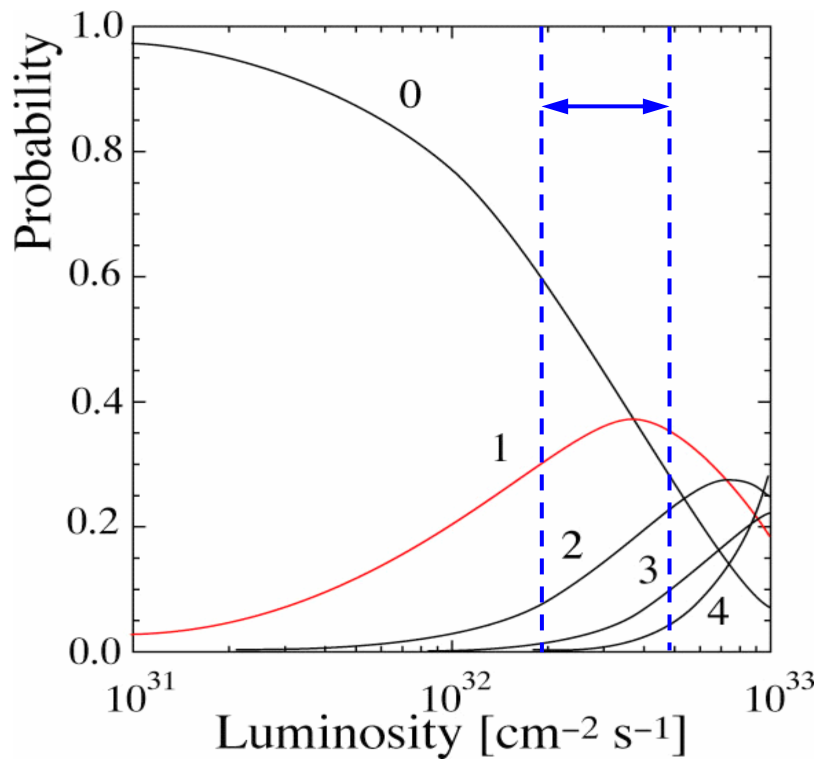
b-production at LHCb



- LHC Luminosity @ LHCb: $2\text{-}5 \times 10^{32}\ cm^{-2}s^{-1}$
- σ_{bbar} = 500 μb
- $\sigma_{inelastic}$ = 80 mb

1 LHCb year = 2 fb^{-1} = 10^{12} $b\bar{b}$

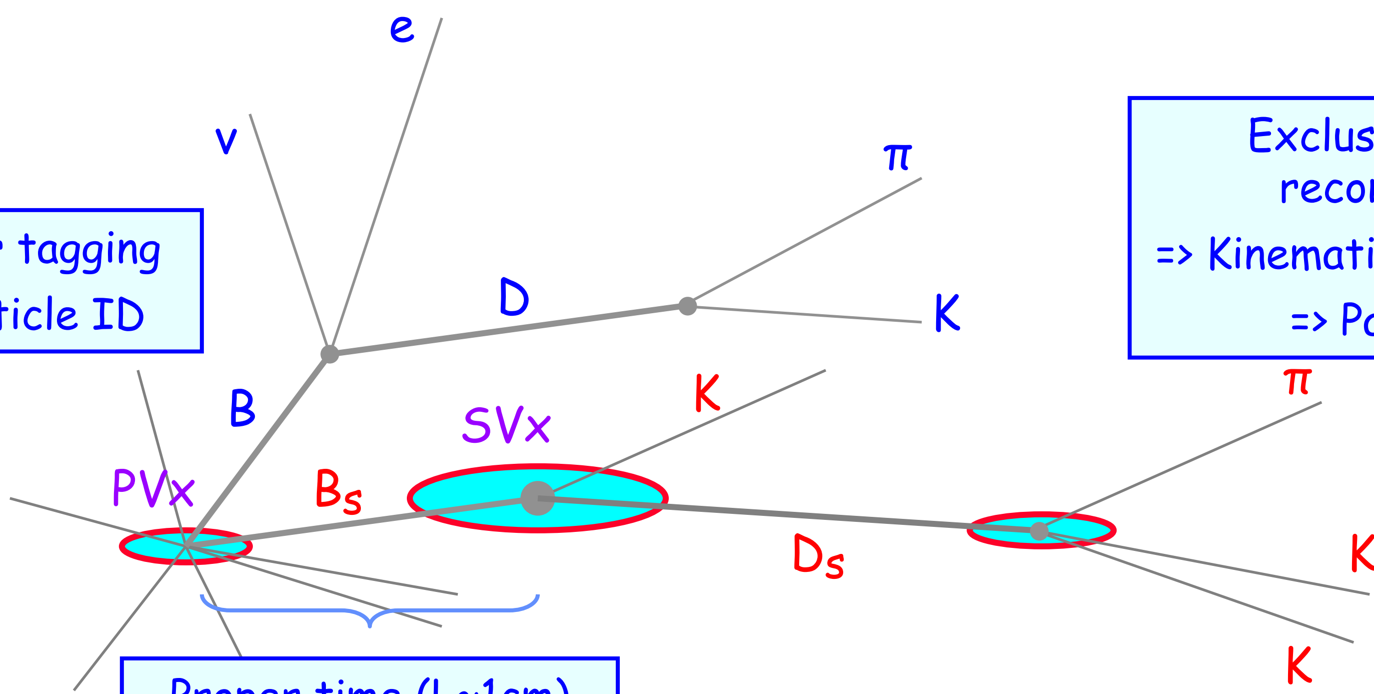




Detector requirements

Example: Decay: $B_s \to D_s K$, $D_s \to \Phi\pi$

Flavour tag: $B \to Dl\nu$



Flavour tagging
=> Particle ID

Exclusive B-decay reconstruction
=> Kinematics measurement
=> Particle ID

Proper time (L~1cm)
Fast Bs oscillations
=> Precise vertexing

+ Efficient trigger
+ Control of systematics

The LHCb detector: kinematic measurements

Charged tracks

γ, π^0

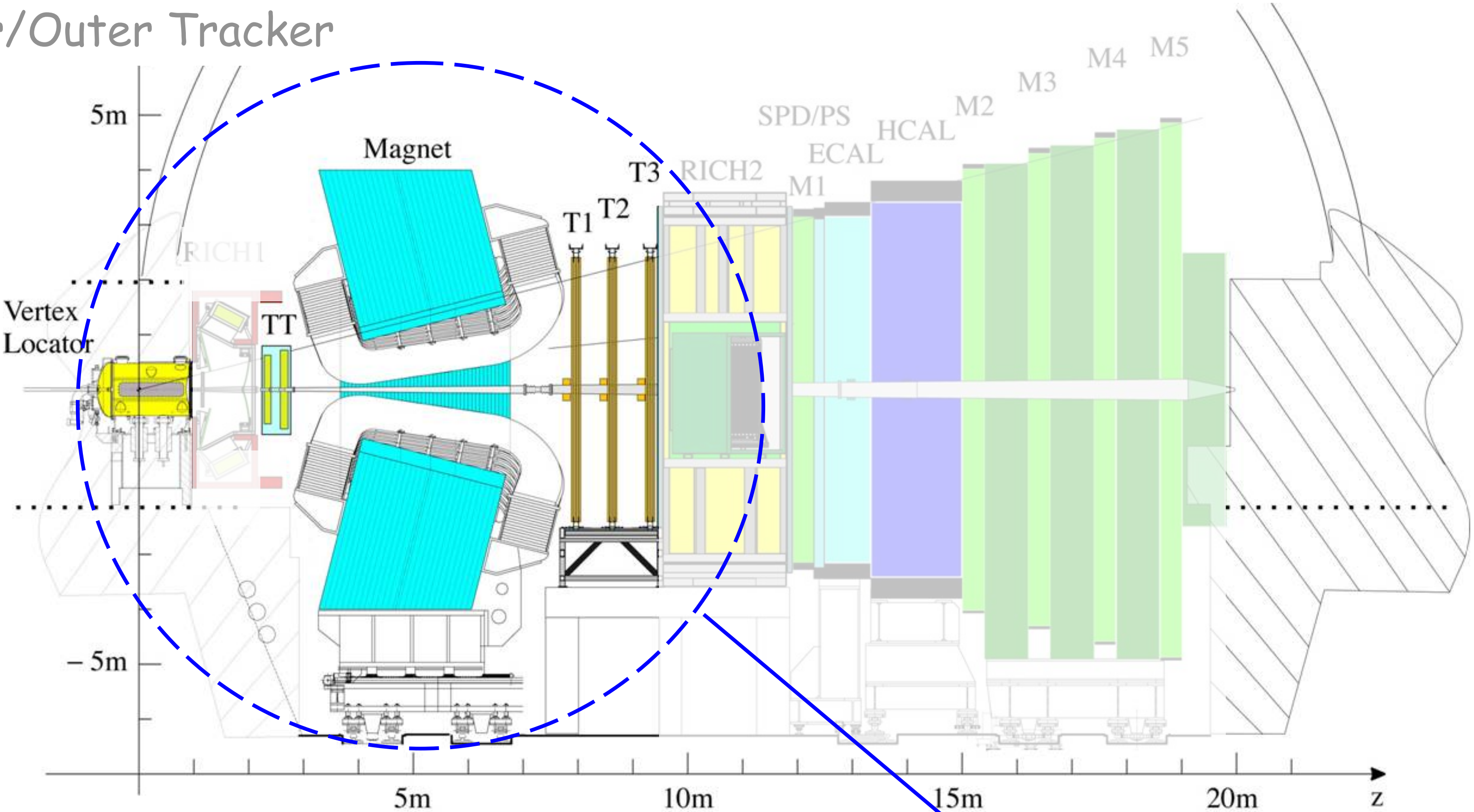
Vertex LOcator

Trigger Tracker

Inner/Outer Tracker

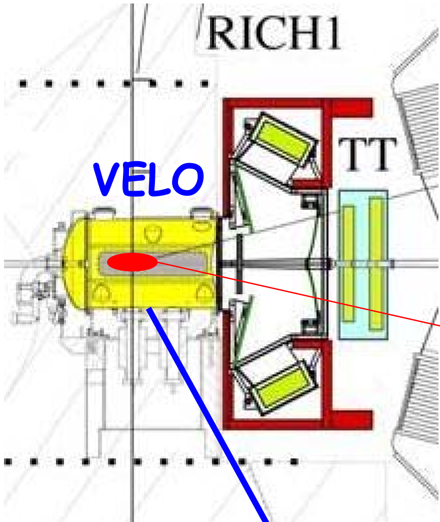
Magnet

Calorimeter

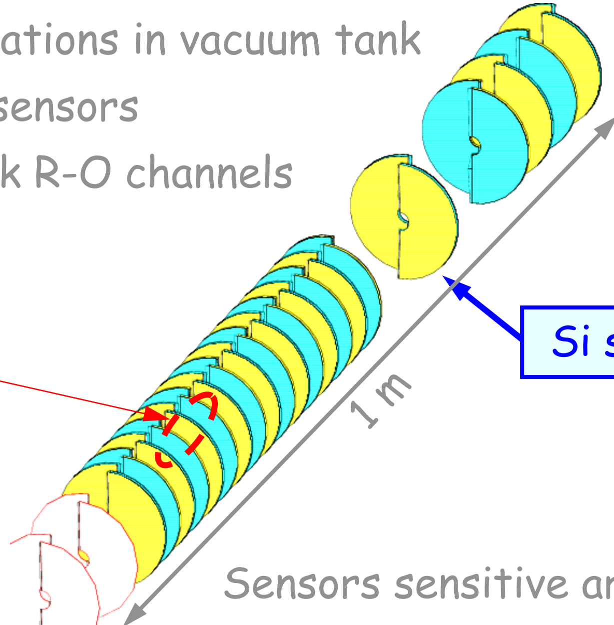


->Talk by Matthew Needham

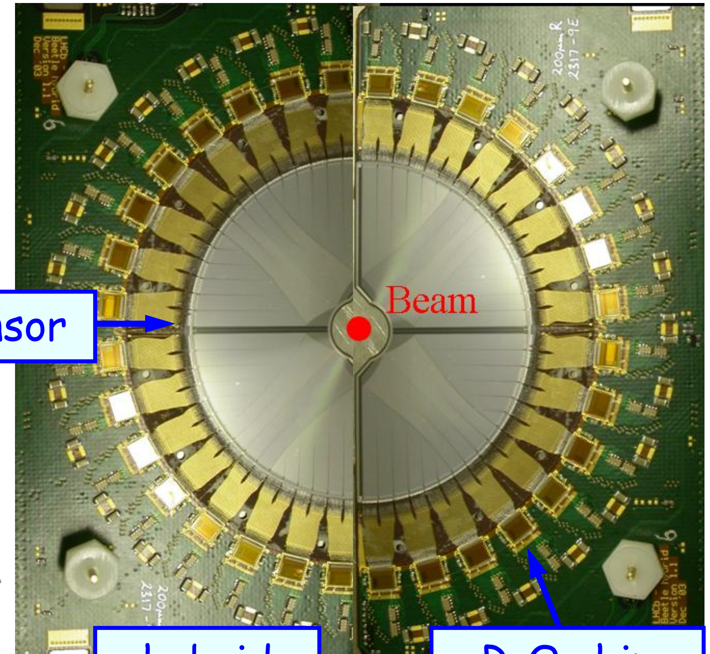
VErtex LOcator



- 21 stations in vacuum tank
- R/φ sensors
- ~180k R-O channels



Si sensor



hybrid

R-O chip

Sensors sensitive area
8mm from beam line
(30 mm during injection)

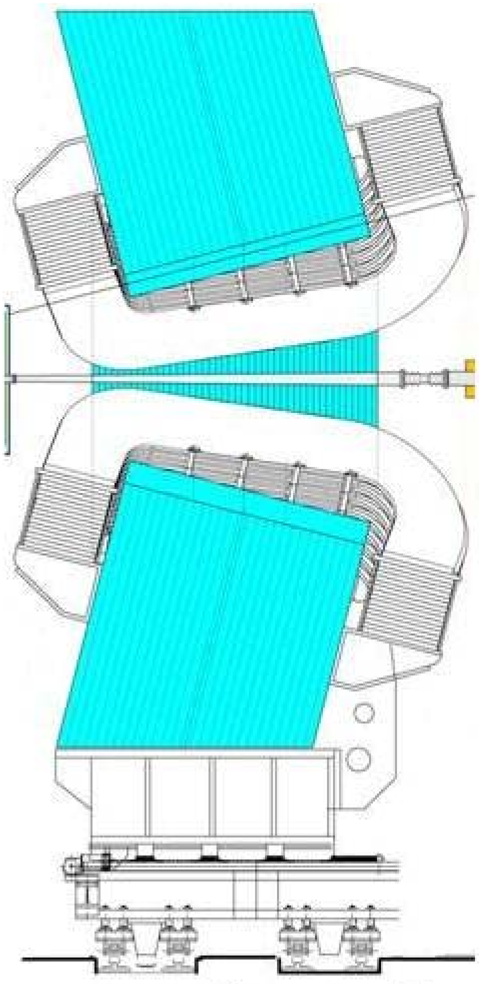
Vacuum vessel arrived at NIKHEF in 04/2005

- PVx position resolution:
  x,y: ~ 8 μm
  z: ~ 44 μm
- IP precision: ~ 30 μm

- VELO in the TestBeam in 2006
  -> study of pattern recognition, alignment, …

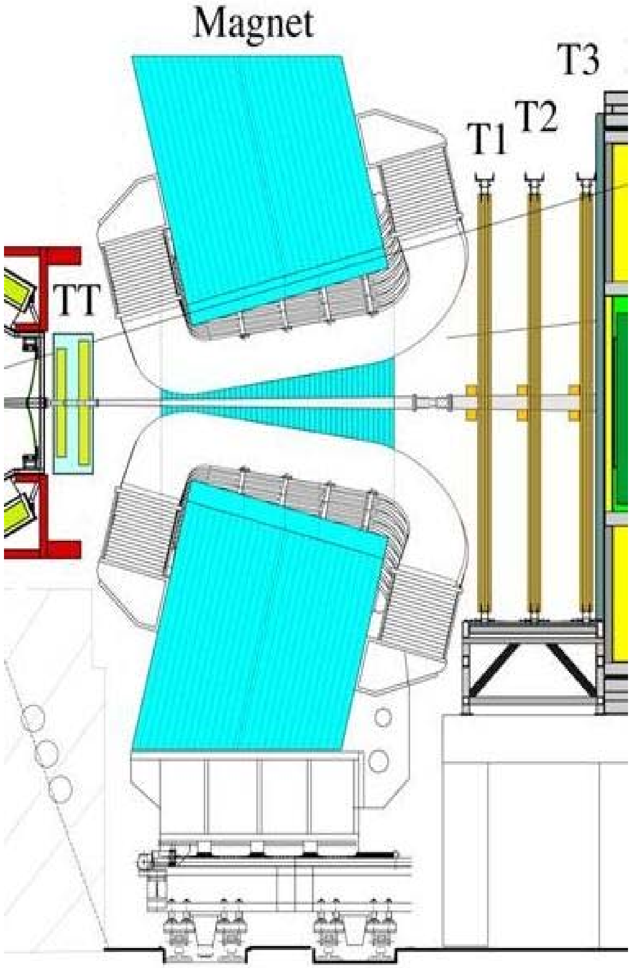
Magnet

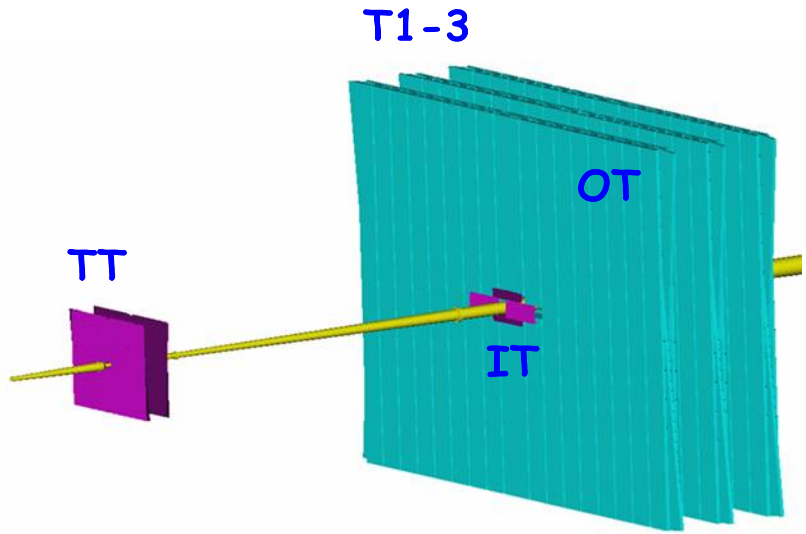
- $\int Bdl$ = 4 Tm
- Warm dipole magnet (Al), Fe yoke = 1600 t
- Daily reverse field to reduce systematics



Installed and commissioned in 2004
Field mapping ongoing

Tracker





- Trigger Tracker

  Silicon Strip, 1.6 x 1.3 m^2

  => 144k channels
- Inner Tracker

  Silicon Strip, 1.2 x 0.6 m^2

  => 129k channels
- Outer Tracker → 60% of chambers produced

  Straw tubes, 5.6 x 4.6 m^2

  => 54k channels

Sensor ladders →

Sensors

Electronics hybrid

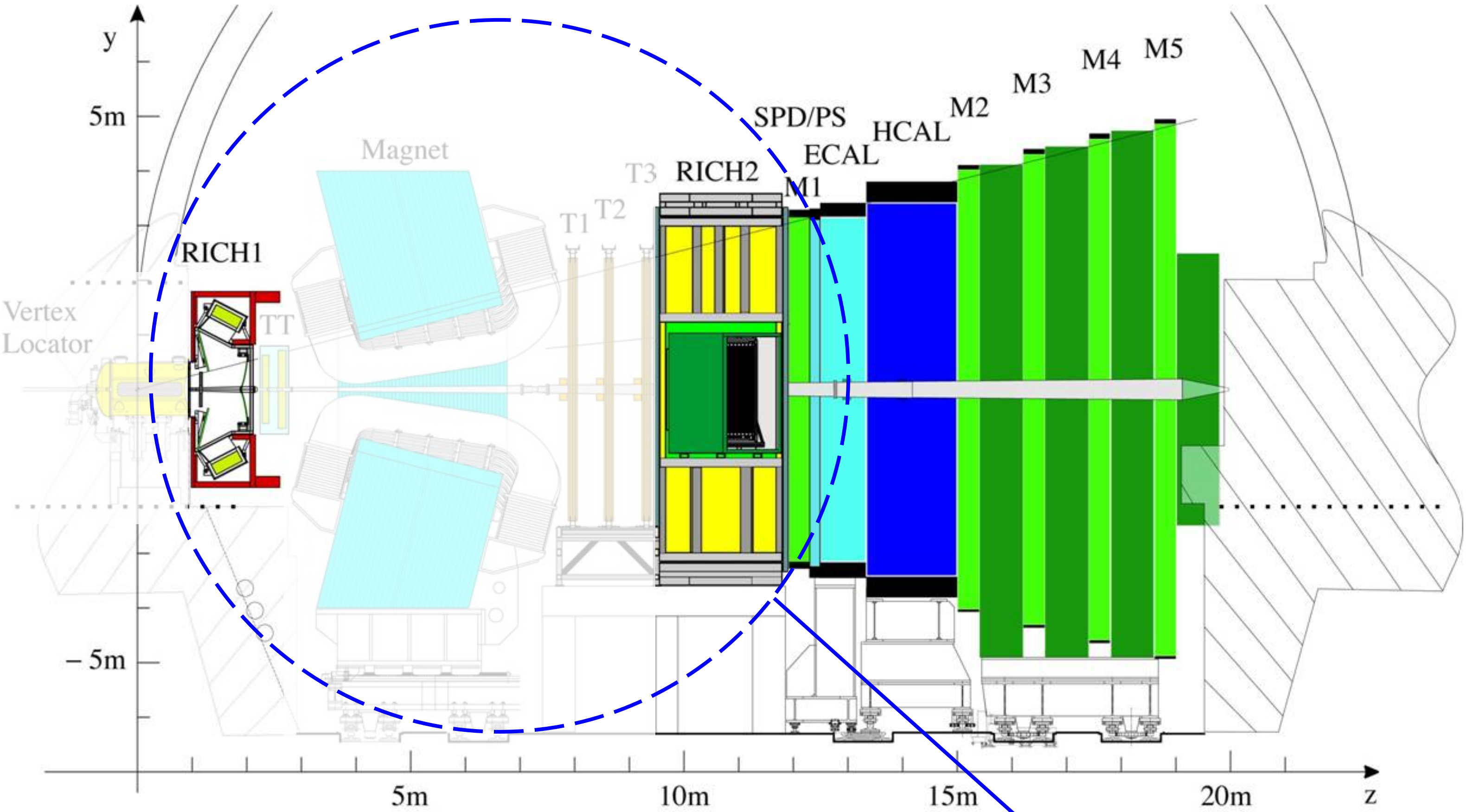
- Efficiency ~94% (p>10 GeV/c)
- Ghost rate ~3% (p_T>0.5 GeV/c)
- Momentum resolution ~0.4%

The LHCb detector: particle ID

$\pi/K/p$ — RICH system

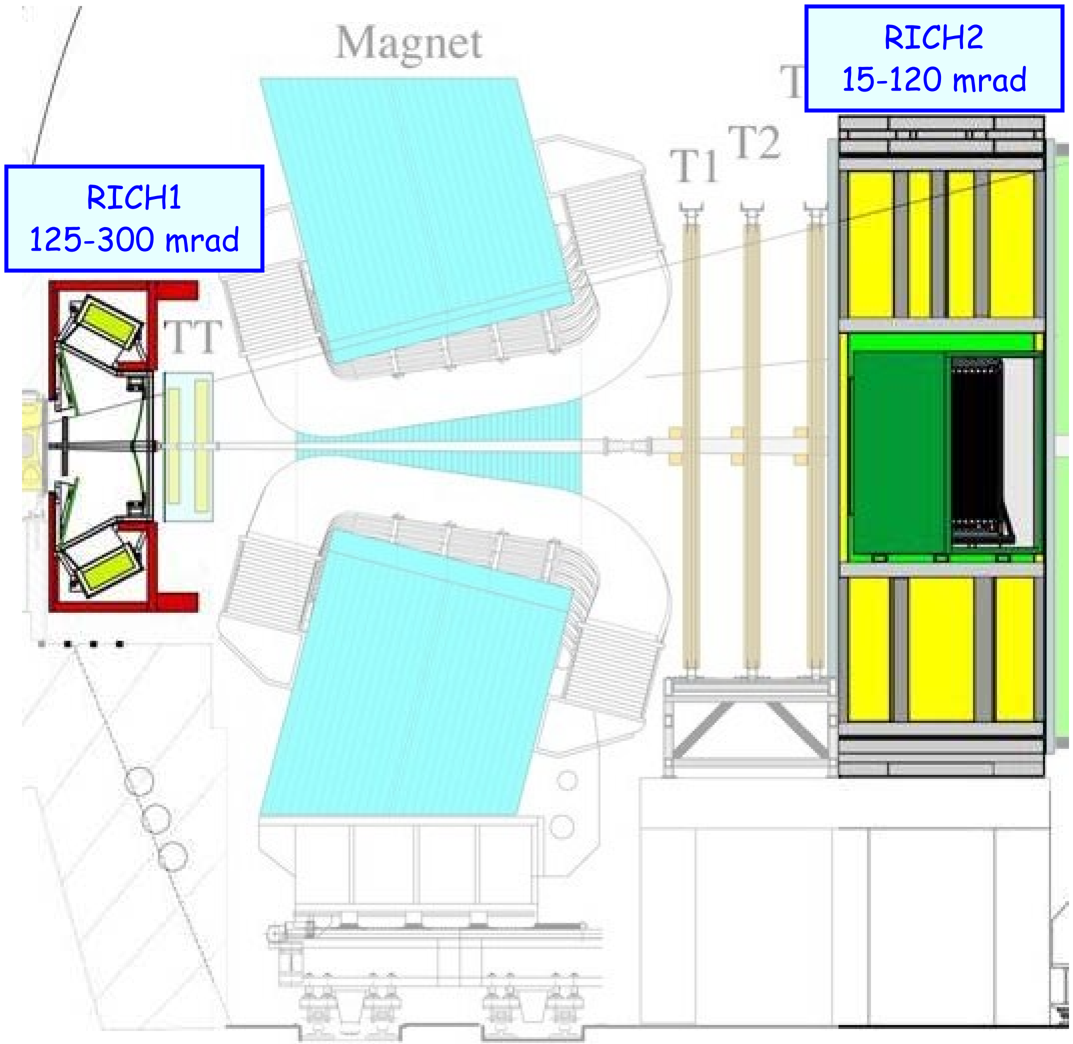
e, γ, π^0 — Calorimeter

μ — μ -system



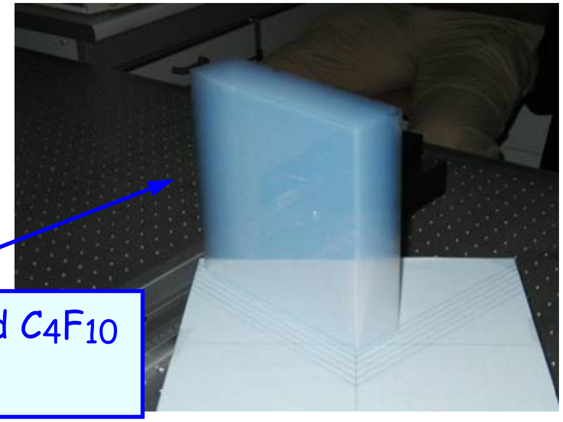
-> Talk by Tito Bellunato

RICH system



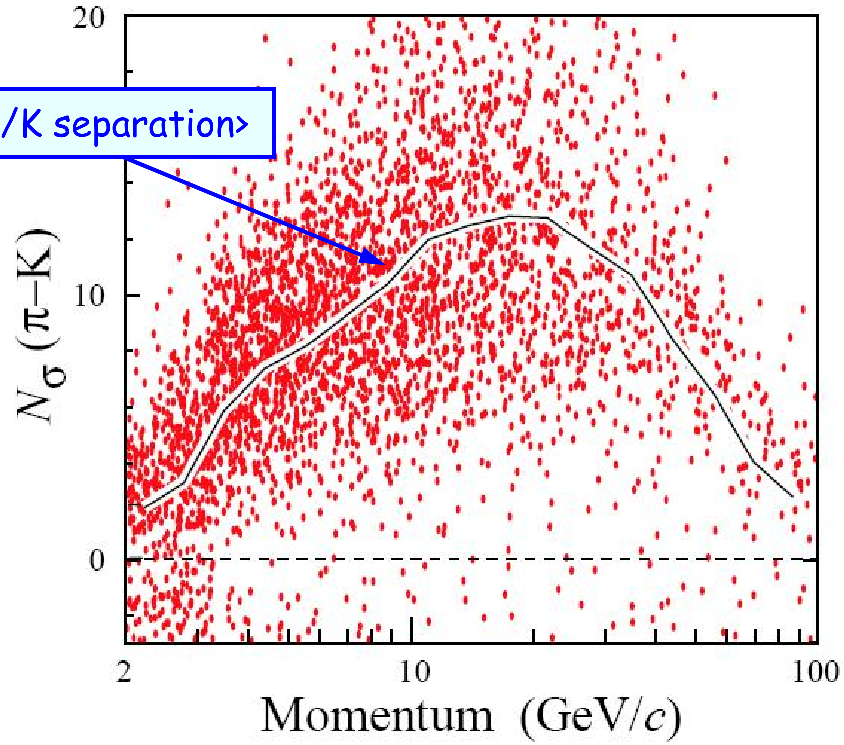
RICH1
125-300 mrad

RICH2
15-120 mrad



RICH1: Aerogel and C_4F_{10}
RICH2: CF_4

π/K separation for true pions
from B->ππ events



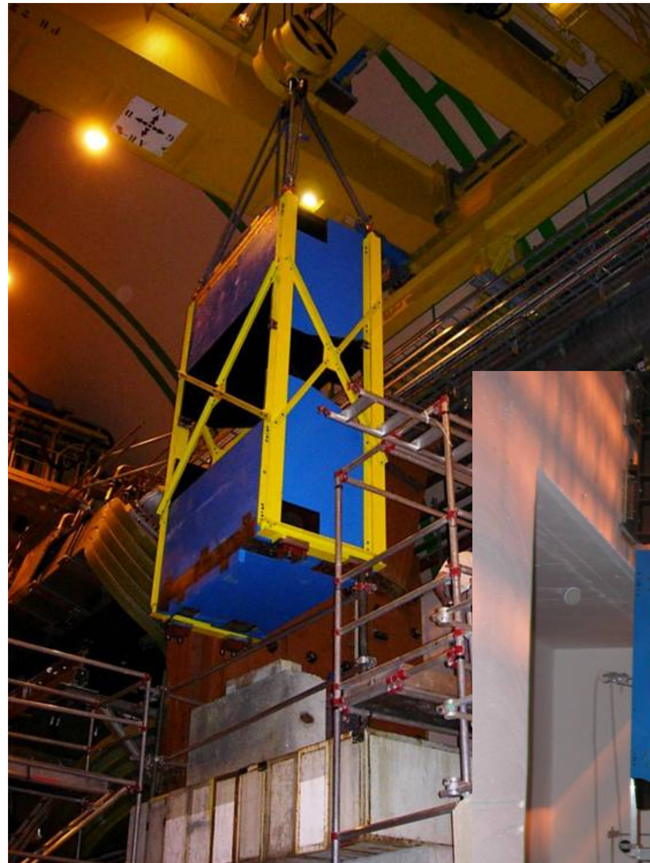
<π/K separation>

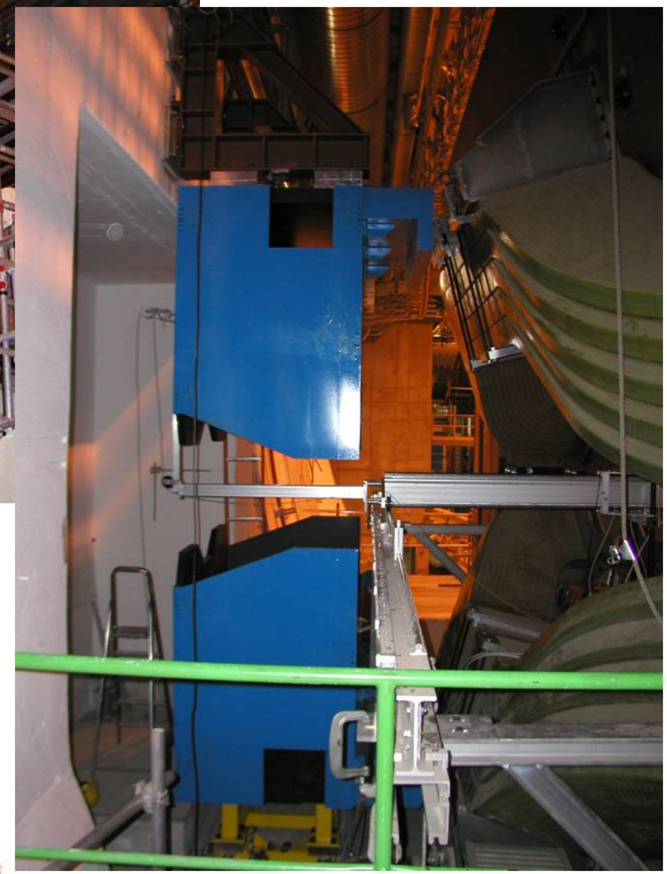
Photon detectors: Hybrid PhotoDiodes (HPD)

RICH system

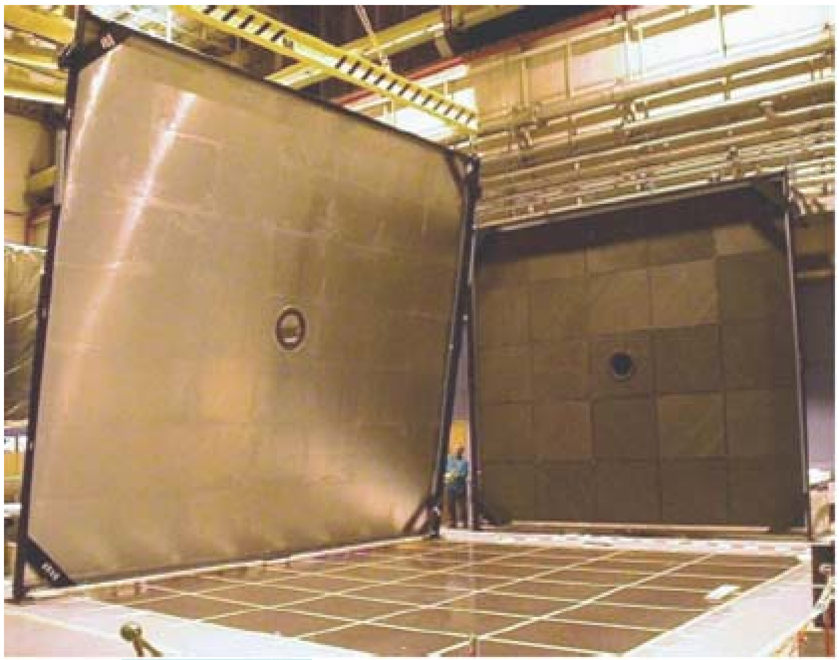
Contract for 500 HPDs signed

Delivery starting from 07/2005





Installation of RICH1 shielding in the LHCb detector

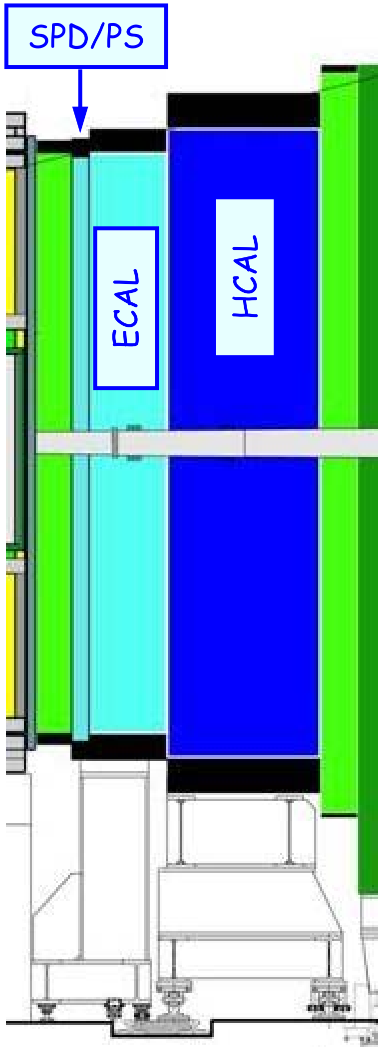


Entrance/exit windows of RICH2

Calorimeter

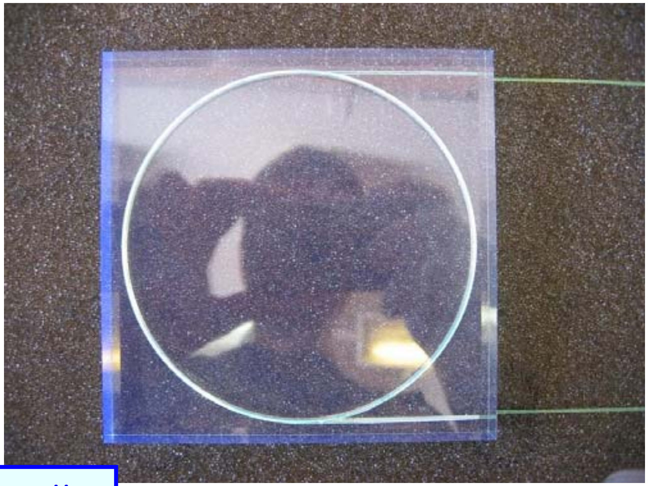
- Scintillator Pad Detector / Preshower (SPD/PS)
- Electromagnetic calorimeter (ECAL)
- Hadronic calorimeter (HCAL)

projective geometry, variable granularity

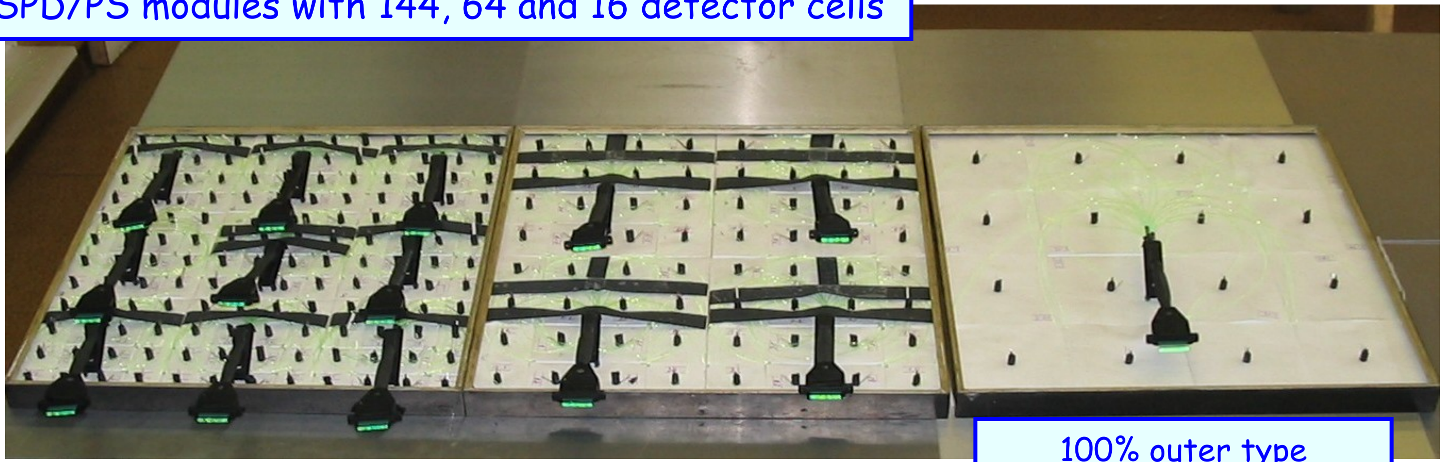


SPD/PS

- Sc-Pb-Sc 15mm-14mm-15mm
- 2 x 6k detector cells/R-O channels
- Deep groove design of cell
- 2.5 X_0 depth
- *Production ongoing*



SPD/PS modules with 144, 64 and 16 detector cells

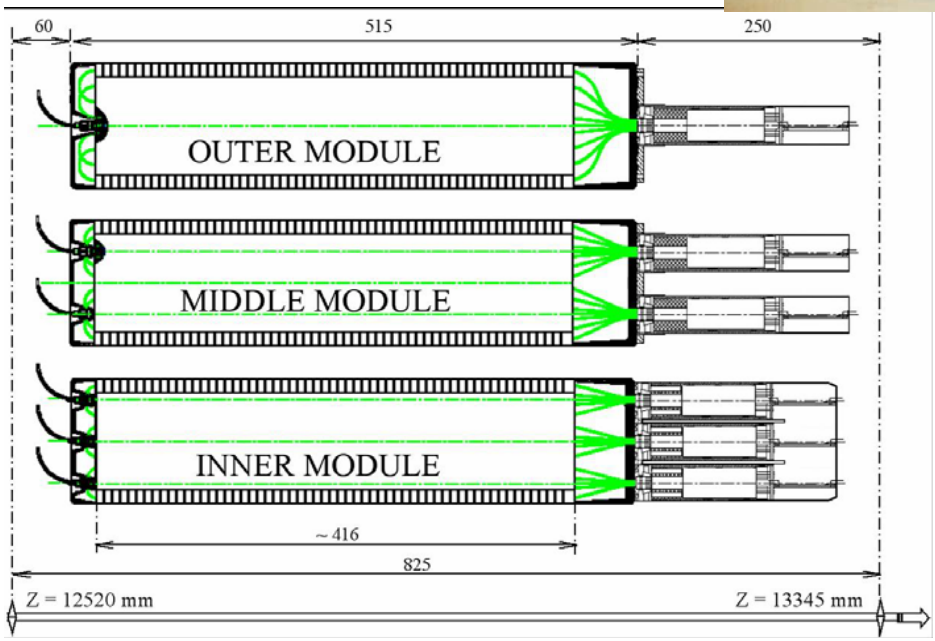


100% outer type modules produced

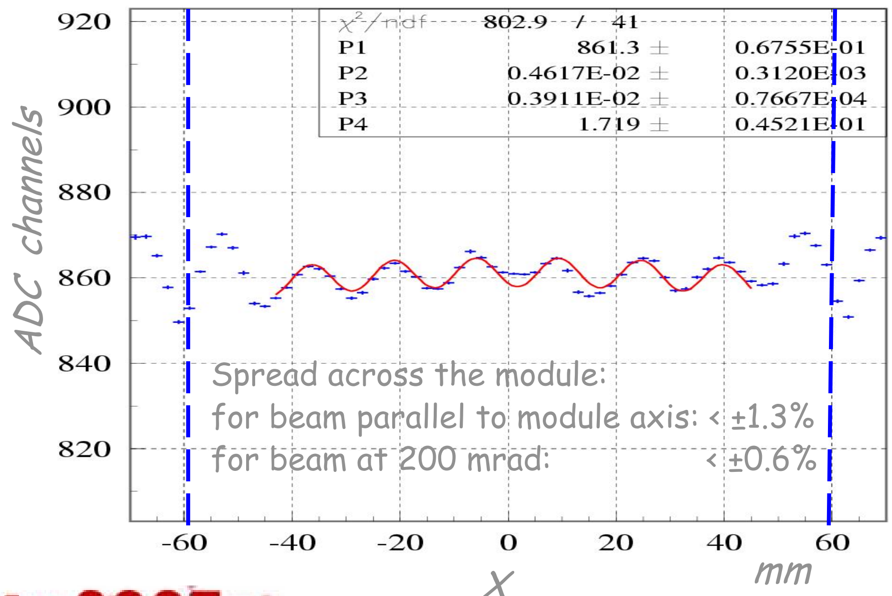
Calorimeter: ECAL

- Shashlyk technology
- 6k detector cells/R-O channels
- Volume ratio Pb:Sc = 2:4 (mm)
- 25 X_0 , 1.1 λ depth
- *Production completed*

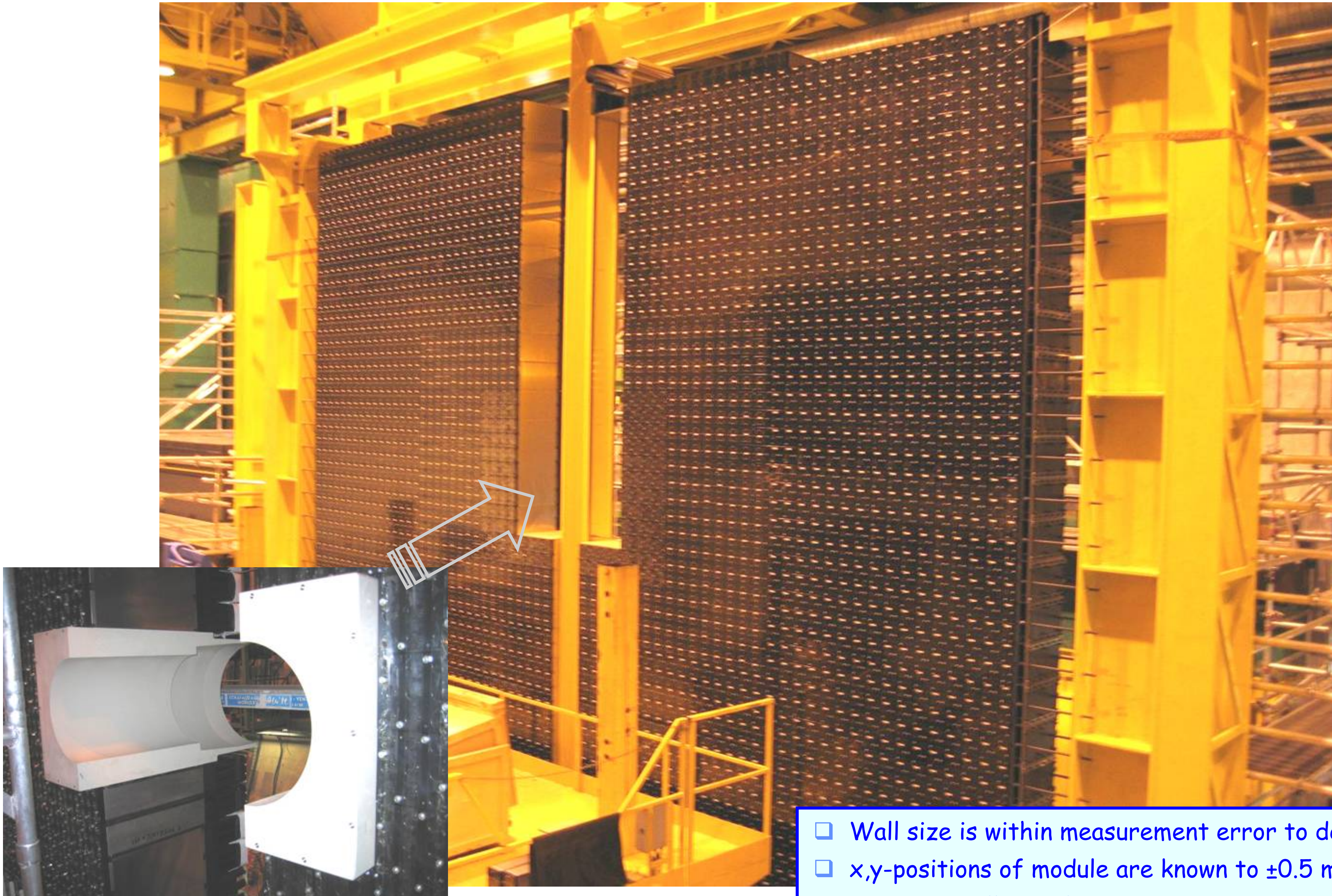
- Light yield: ~3000 ph.e./GeV
- Cell-to-cell spread: r.m.s.<7%
- Energy resolution: $\sigma(E)/E = 10\%/\sqrt{E} \oplus 1\%$



Lateral scan of ECAL module with 50 GeV e-beam



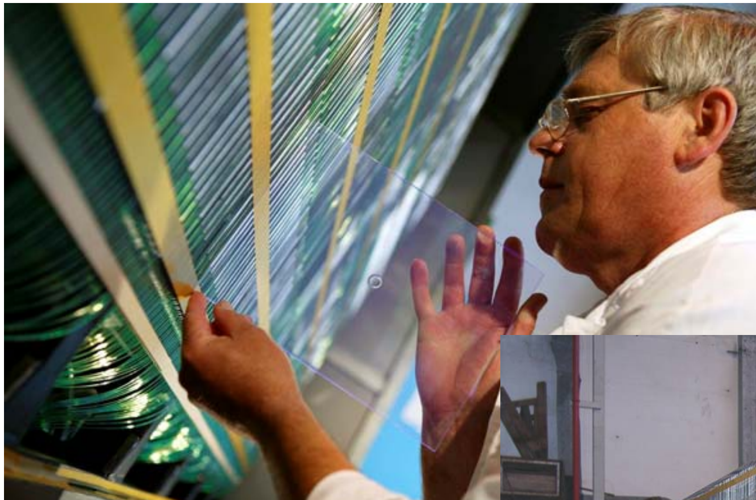
Calorimeter: ECAL



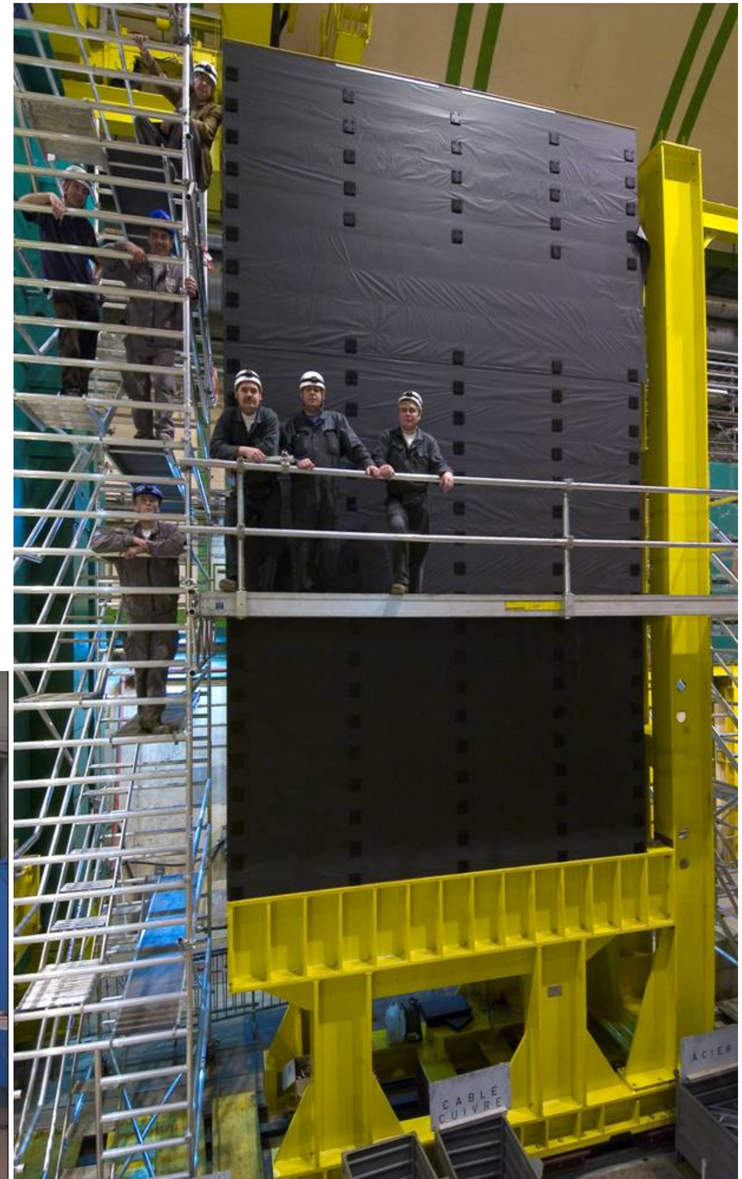
- Wall size is within measurement error to design value
- x,y-positions of module are known to ±0.5 mm
- z-position: all modules within ±2 mm

Calorimeter: HCAL

- Fe-Scintillator tile calorimeter
- 1.5k detector cells/R-O channels
- 5.6 λ depth
- *Production completed*
- Cell-to-cell spread: r.m.s. < 5%

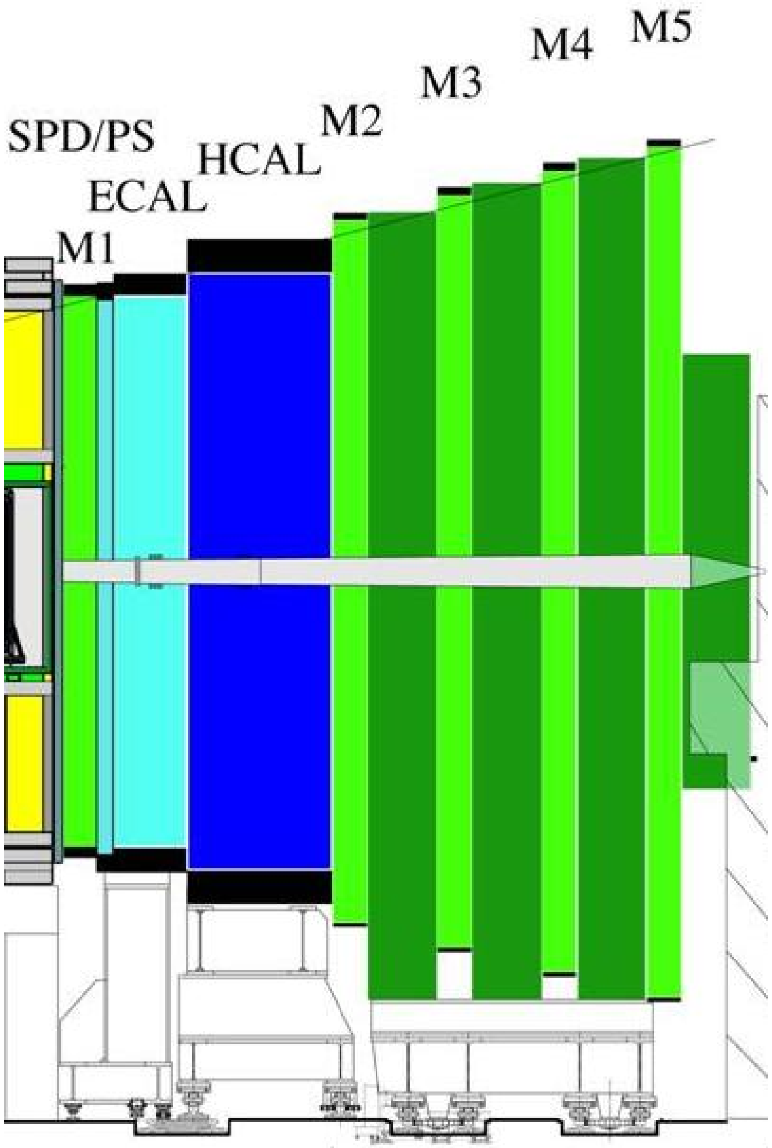


Assembly of HCAL module

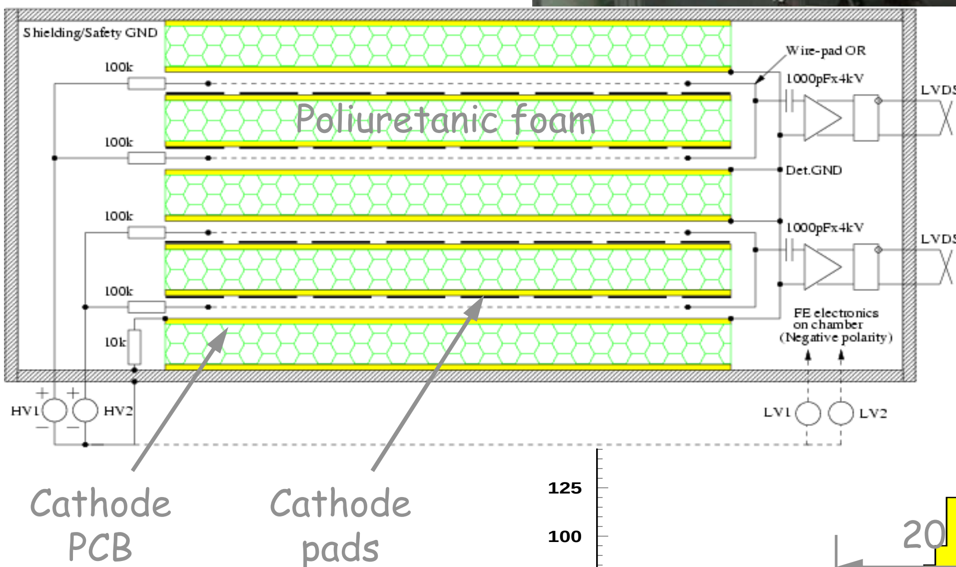


1/2 HCAL is installed in the detector

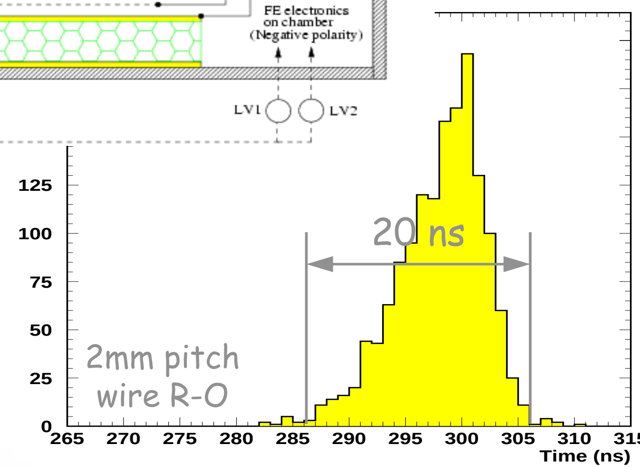
Muon detector



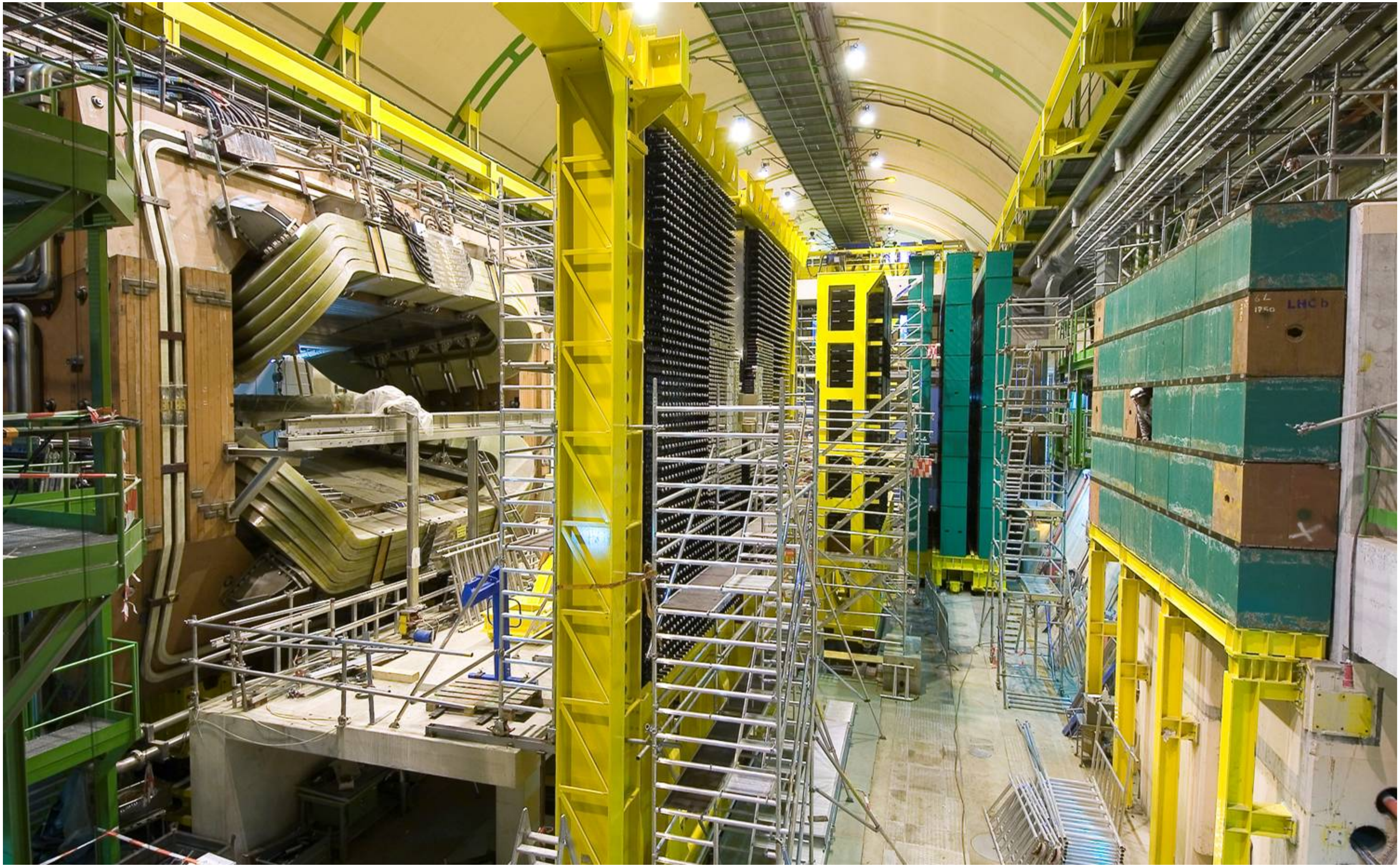
- 5 stations with projective pad R-O
- Production at 6 sites
- In total: 1368 MWPCs
- *Produced and tested:* 450 MWPCs (~30%)



- Efficiency ~95%
- π-misID rate <1%

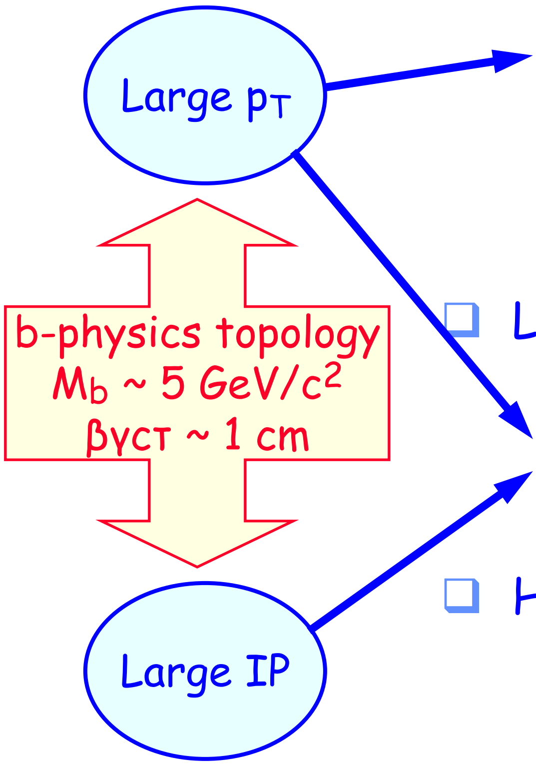


A very busy time in the LHCb cavern

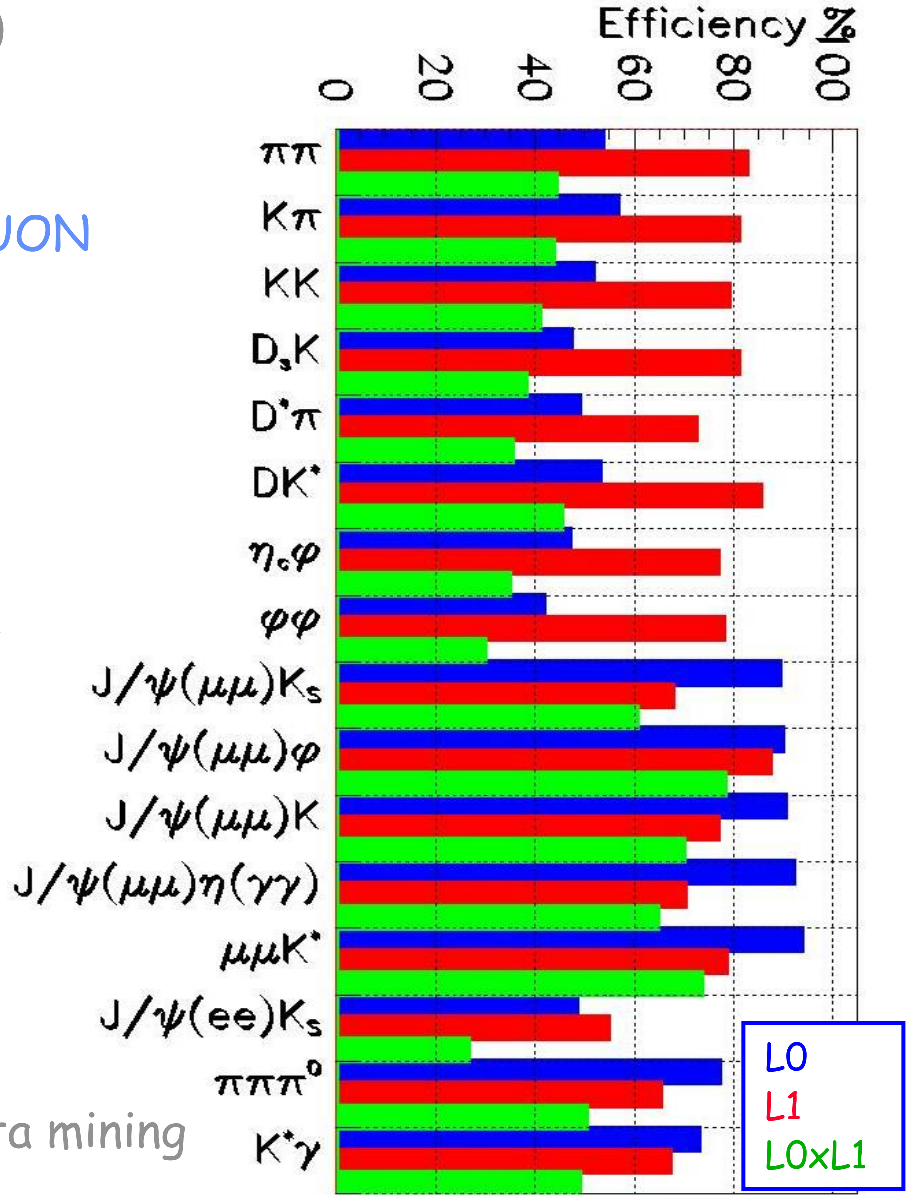


Trigger

-> talk by Frederic Teubert



- Level 0 (40 MHz -> 1 MHz)
  -> hardware
  - high-p_T e, γ, π^0, μ, h
    => CALO, MUON
  - pile-up veto
    => VELO
- Level 1 (1 MHz -> 40 kHz)
  -> software
  - large IP and p_T tracks
    => VELO, TT
- High Level Trigger
  -> software
  - complete event info
    => ALL
  - ~offline selection
- -> 2 kHz on tape
  - -> systematics and data mining



Baseline measurements

B_s oscillations frequency, phase and $\Delta\Gamma_s$

- $B_s \to D_s \pi$
- $B_s \to J/\Psi\, \Phi$, $J/\Psi\, \eta$, $\Phi\, \eta_c$

Measurement of γ=-Arg V_{ub}

- $B_s \to D_s K$
  only tree diagrams -> no NP
- $B_d \to \pi\pi$, $B_s \to KK$
  U-spin symmetry, NP in gluonic penguins
- $B_d \to D^0 K^*$, $\overline{D}^0 K^*$, $D_{CP} K^*$
  Dunietz-Gronau-Wyler method, NP in $D\overline{D}$-mixing

Rare decays, search for NP

- $B_d \to K^*\gamma$, $\omega\gamma$, $B_s \to \Phi\, \gamma$
- $B_s \to \Phi\Phi$, $B_d \to \Phi K_s$
- $B_d \to K^*\, \mu\mu$
- $B_s \to \mu\mu$

Event generator: Pythia+QQ

Full detailed Geant simulation of detector

pile-up and spill-over included

Realistic digitization and reconstruction with full pattern recognition

Realistic L0, L1 trigger simulation

Assumption: Major background:

$b\bar{b}$-inclusive events

large p_T, IP, secondary vertices, multiplicity

Toy MC used for sensitivity studies

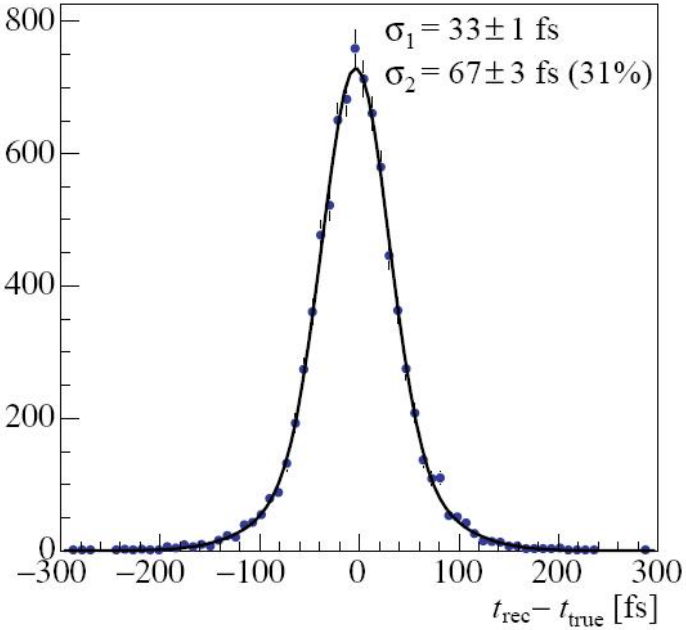
acceptance and resolutions parameterized from full MC

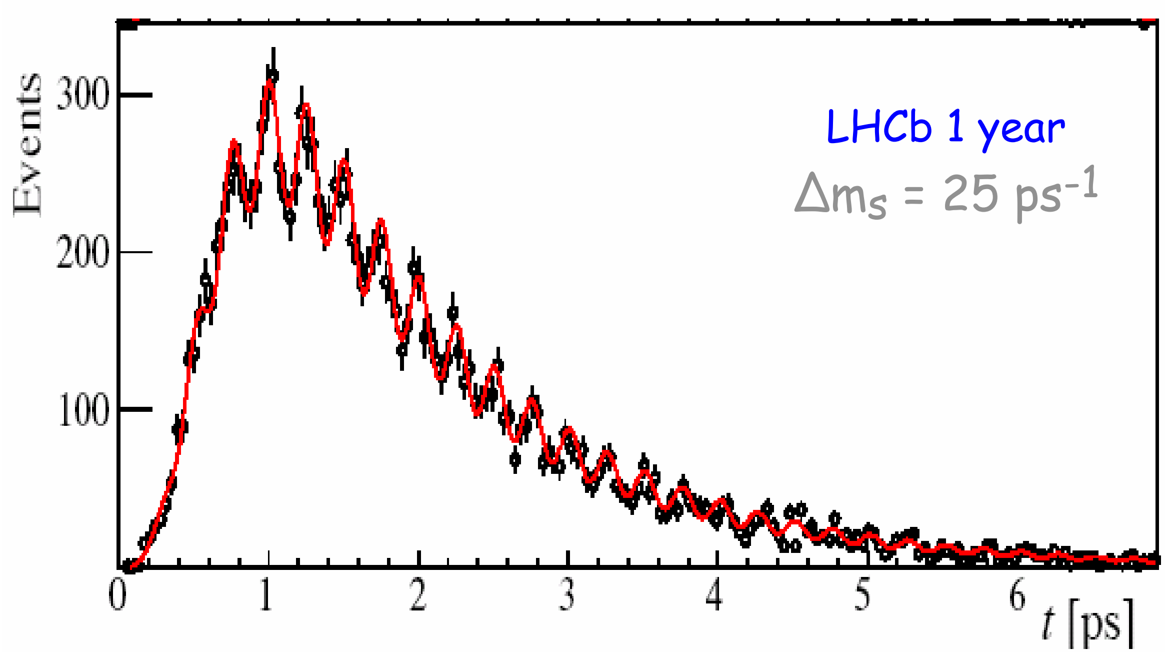
Reconstruction/analysis software environment **-> talk by Patrick Koppenburg**

Δm_s measurement: $B_s \to D_s\pi$

$D_s \to KK\pi$

Proper time resolution ~40 fs





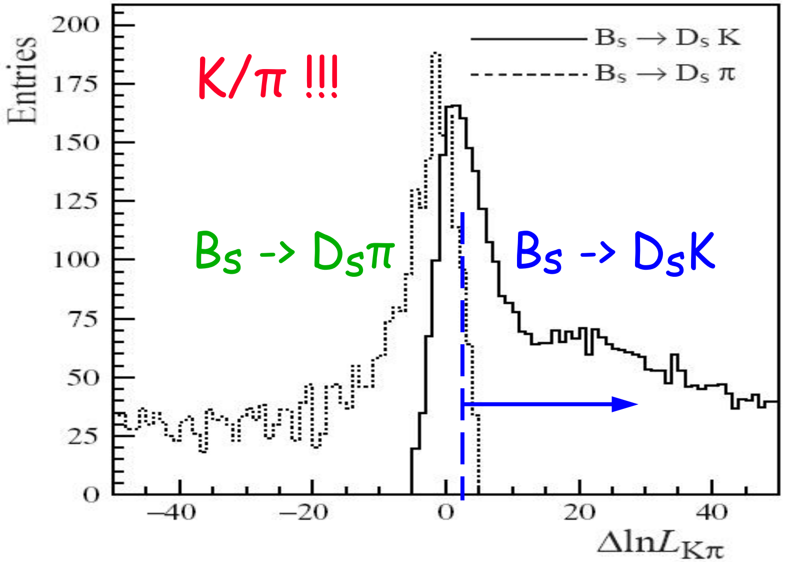
- 82k events/year
- B/S = 0.32 ± 0.10

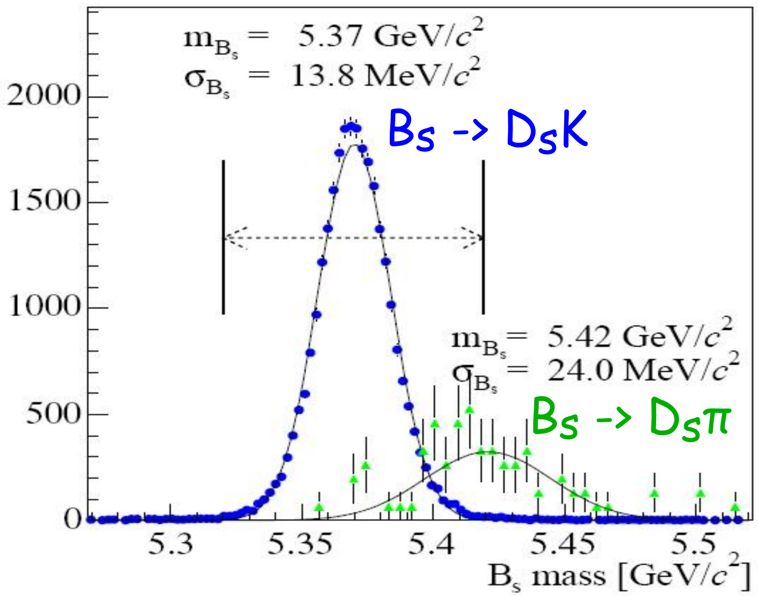
- 5σ measurement in 1 year of running for Δm_s up to 68 ps^{-1}
  (far beyond Standard Model expectation Δm_s < 26 ps^{-1})
- Once oscillations are established, determine Δm_s with $\sigma(\Delta m_s) \sim 0.01_{stat}$ ps^{-1}

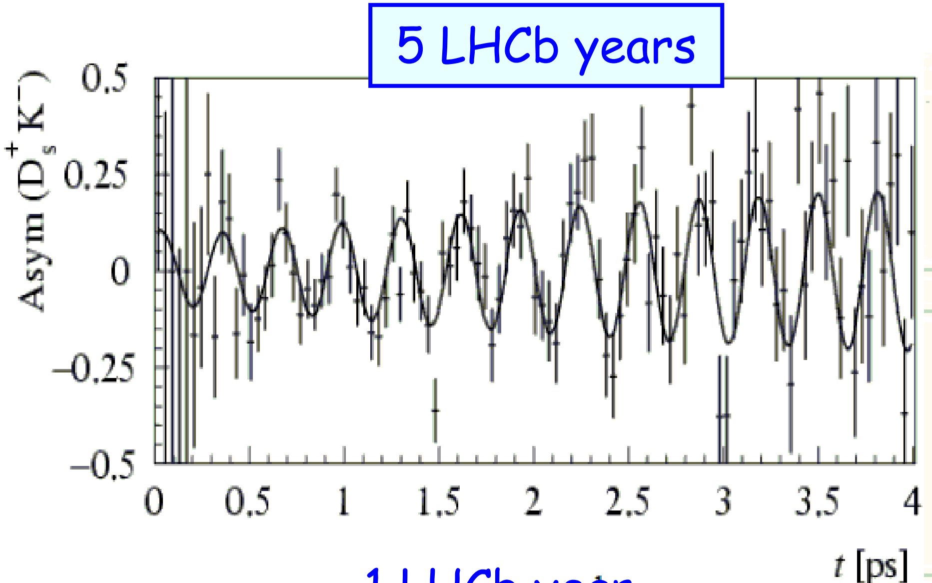
γ measurement: $B_s \to D_s K$

$D_s \to KK\pi$

- 5.4k events/year
- B/S < 1
- Measures γ-2χ



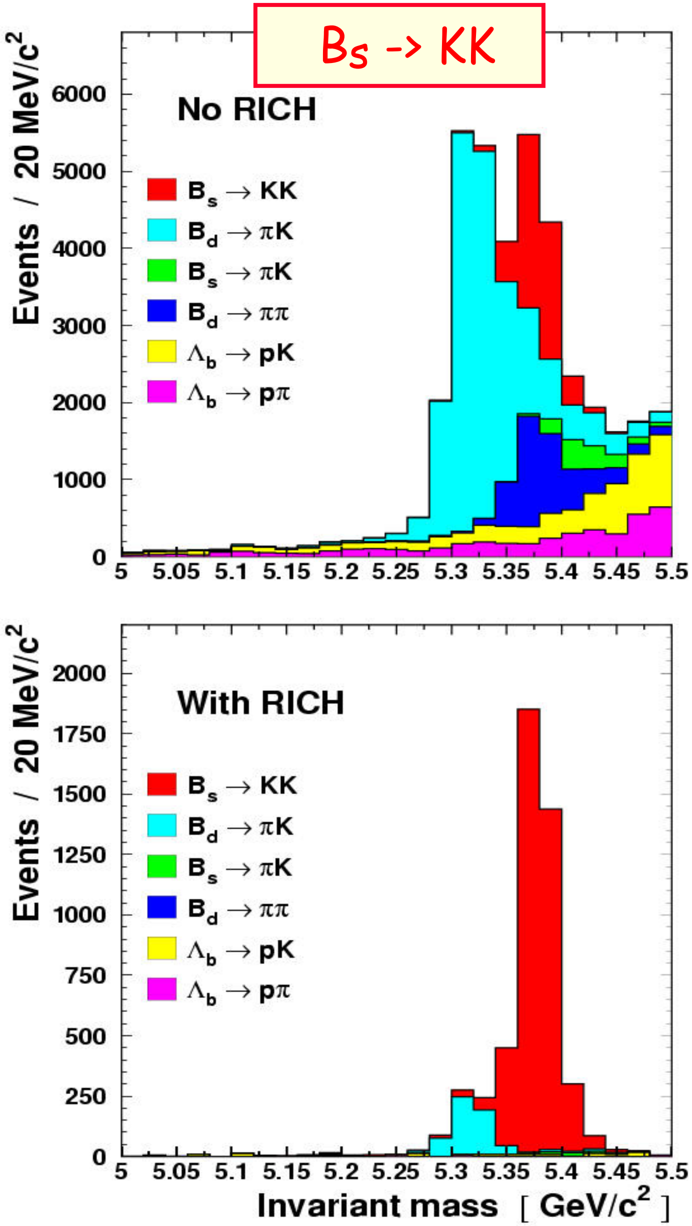




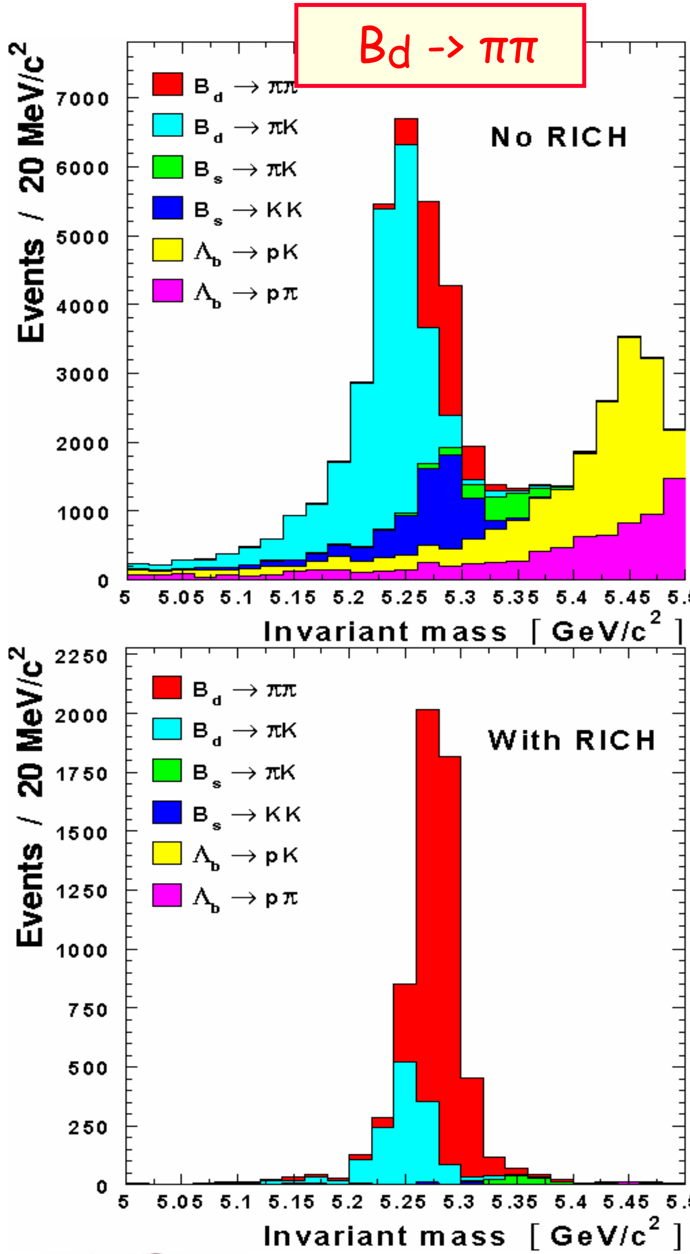
1 LHCb year

Δm_s, (ps^{-1})	20	25	30
σ(γ), (°)	14.2	16.2	18.3

$B_d \to \pi\pi$, $B_s \to KK$



K/π !!!



γ measurement: $B_d \to \pi\pi$, $B_s \to KK$

- Measures γ
- Time-dependent asymmetries for $B_d \to \pi\pi$ and $B_s \to KK$:

$$A_{CP}(t) = A_{dir} \cos(\Delta m\ t) + A_{mix} \sin(\Delta m\ t)$$

- Parameters: γ, $\varphi_d(\varphi_s)$, $P/T = d\ e^{i\theta}$
- Take $\varphi_d(\varphi_s)$ from other measurements
- U-spin symmetry [Fleischer]:

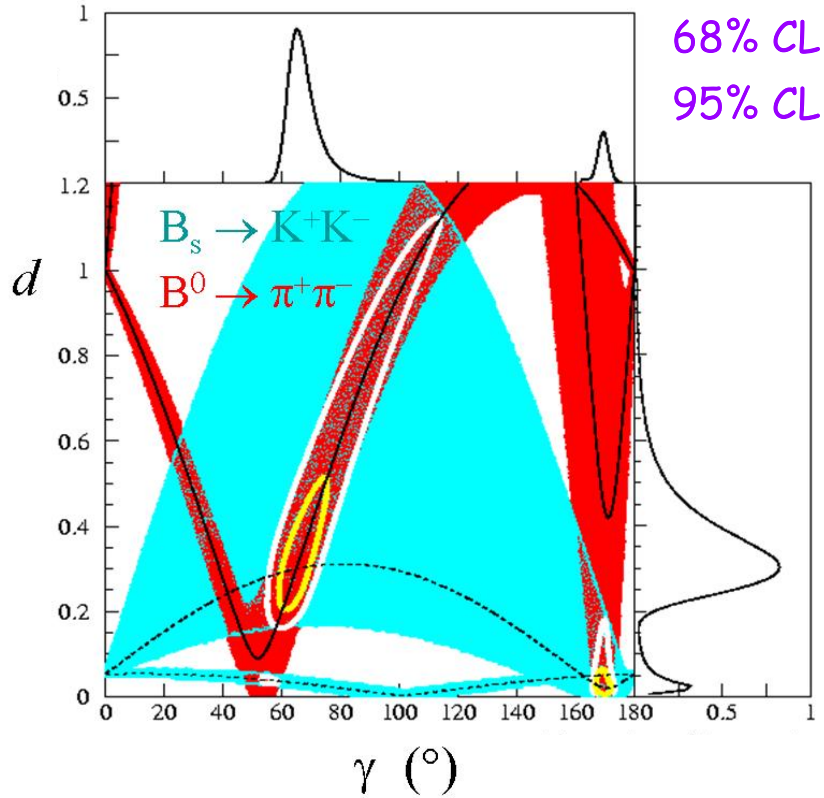
  $d_{\pi\pi} = d_{KK}$ and $\theta_{\pi\pi} = \theta_{KK}$

  => 4 measurements, 3 unknown

  => Solve for γ

- $\sigma(\gamma) \sim 5^o$ in 1 LHCb year
- Uncertainty from U-spin assumption
- Sensitive to new physics in penguins

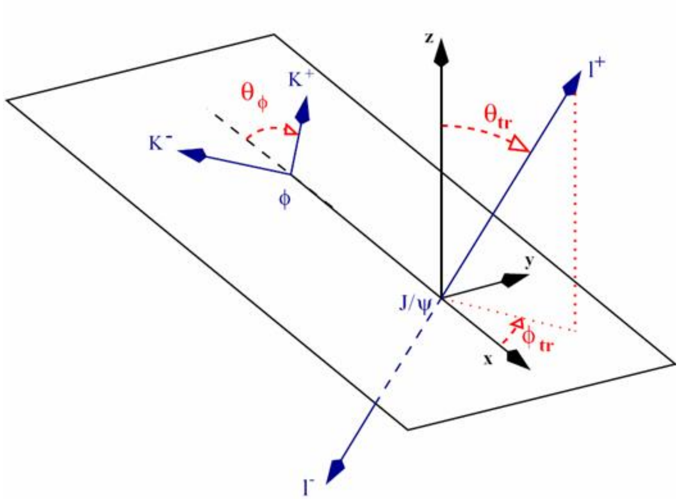
- $B_d \to \pi\pi$ 25k events/year
- $B_s \to KK$ 37k events/year



$B_s \to J/\Psi\ \Phi$

$J/\Psi \to ll$

$\Phi \to KK$



- Non-CP state => partial waves
- Measures $\varphi_S = -2\chi$; $\chi \sim 0.02$ is small
- Simultaneous measurement of $\Delta\Gamma_S$; in SM $\Delta\Gamma_S/\Gamma_S \sim 0.1$

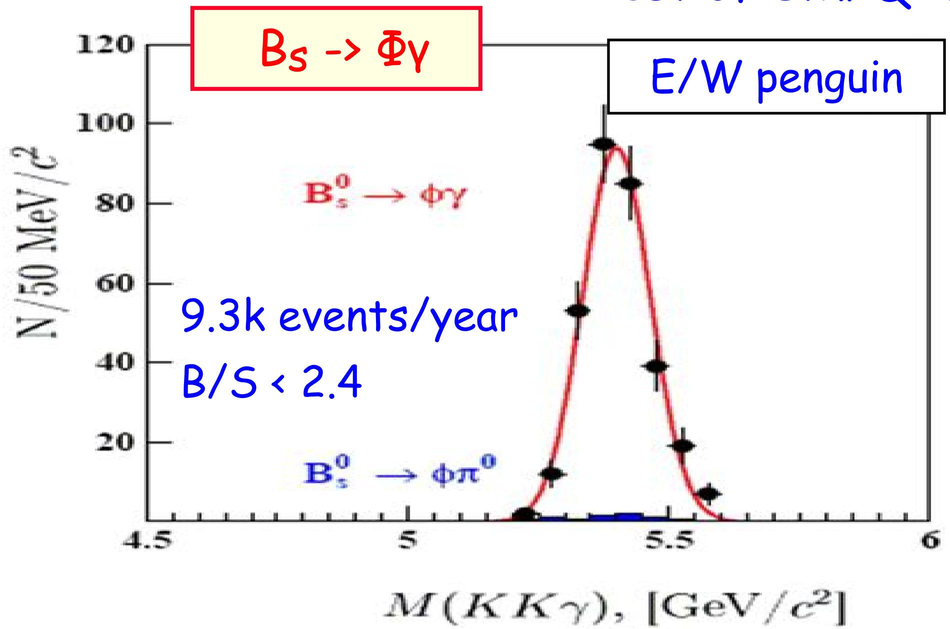
$$\frac{d\Gamma(t)}{d(\cos(\theta_{tr}))} \propto \left[|A_0(t)|^2 + |A_\parallel(t)|^2\right] \frac{3}{8}(1+\cos^2\theta_{tr}) + |A_\perp(t)|^2 \frac{3}{4}\sin^2\theta_{tr}$$

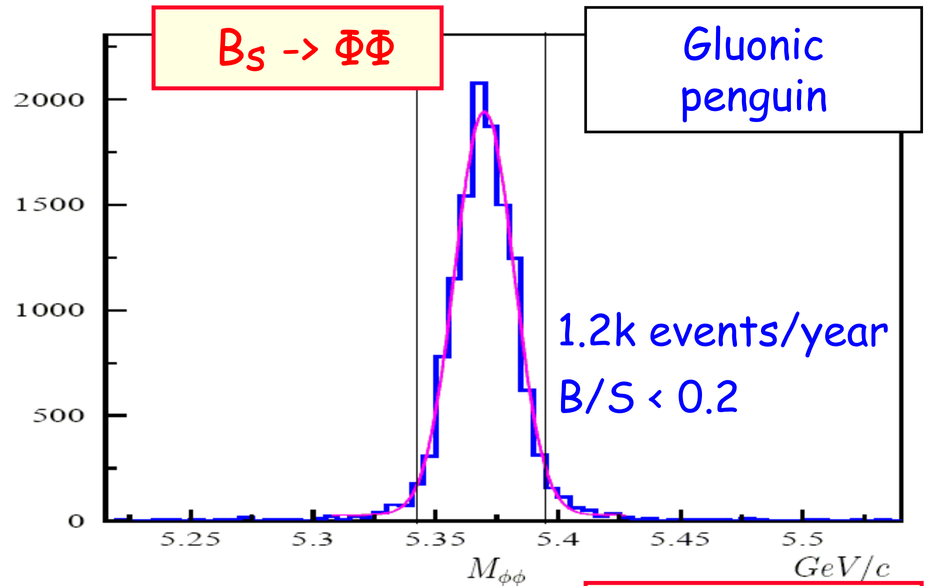
Sensitivity (1 year)	$\sigma(\Delta\Gamma_s/\Gamma_s)$	$\sigma(\phi_s)$ [rad]	Annual yield	B/S
$B^0_s \to J/\psi\ \phi$	0.018	0.06	100k	< 0.3
$B^0_s \to J/\psi\ \eta$	~ 0.025	~ 0.1	7k	< 5.1
$B^0_s \to \eta_c\phi$	~ 0.025	~ 0.1	3.2k	< 1.4
Combined ϕ_s sensitivity		~ 0.05		

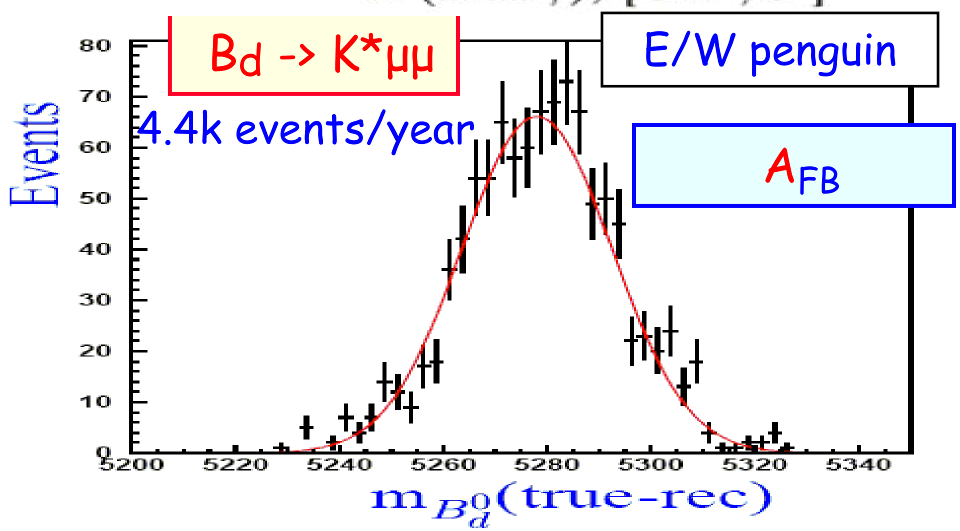
=> 5 years sensitivity $\sigma(\varphi_S) \sim 0.02$

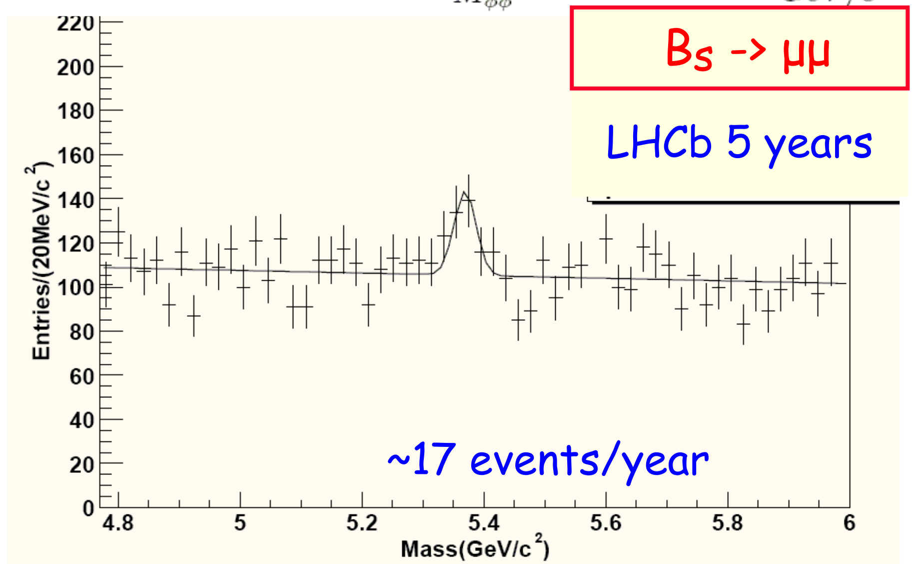
Rare decays

Test of SM/QCD; search for NP

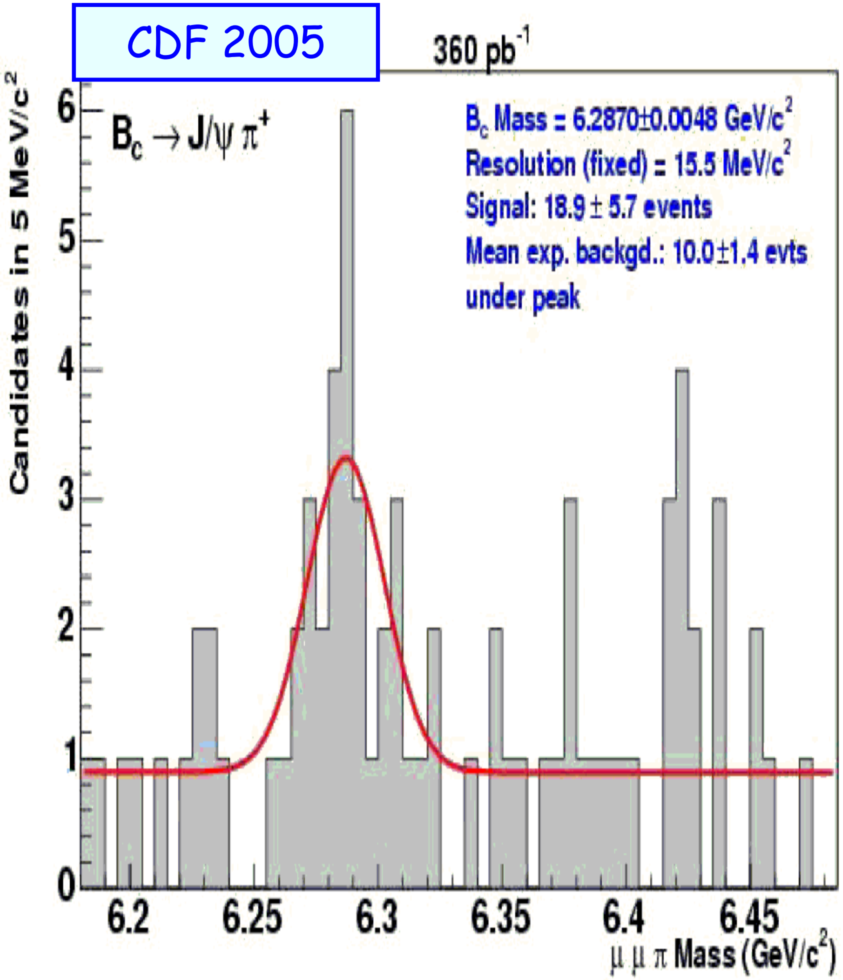




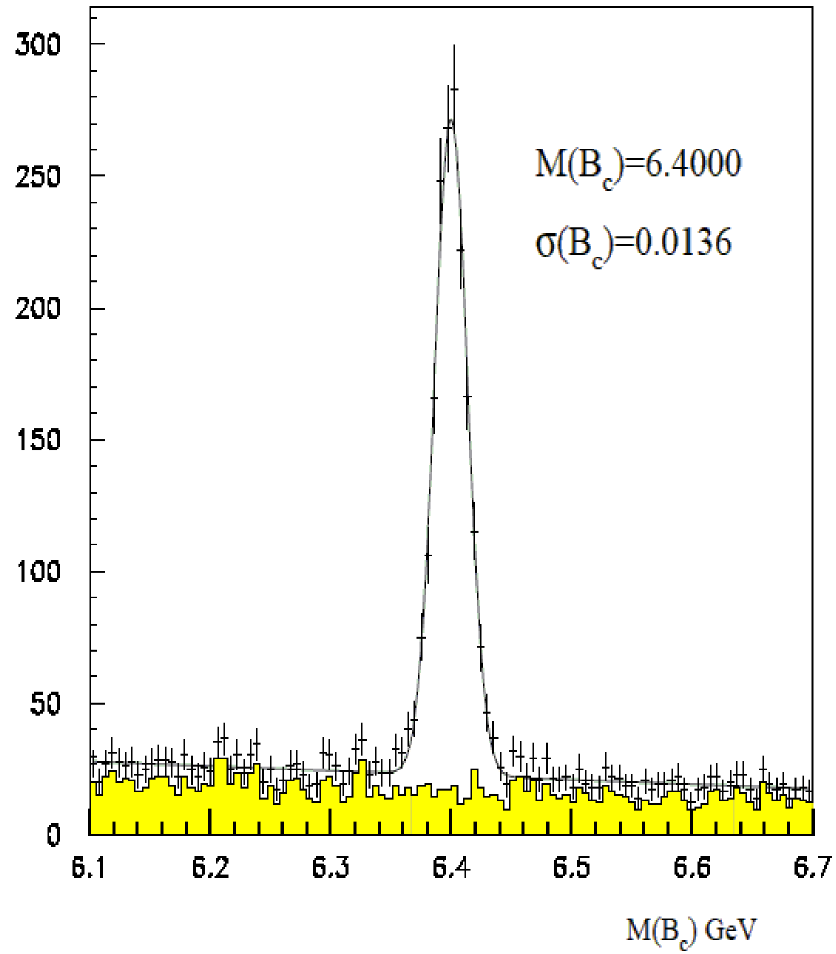




$B_c \to J/\Psi\ \pi$



LHCb ~1.5 month

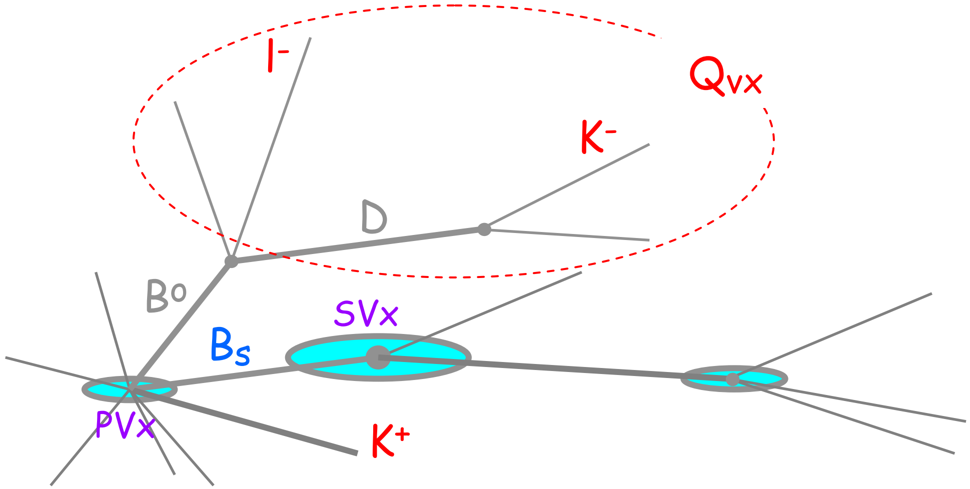


Yield: 14k events/year

B/S < 0.8

Flavour Tagging

Determine the flavour of the signal B-meson at production



Algorithms

- "Opposite side"
  - leptons from semileptonic decays
  - $K^{\pm}$ from b->c->s chain
  - inclusive vertex charge
- "Same side"
  - $K^{\pm}$ from fragmentation accompanying B_s meson

Quality of the flavour tagging

- tagging efficiency ε_{tag} = (R+W) / (R+W+U)
- wrong tag fraction ω = W / (R+W)
- effective tagging efficiency $\varepsilon_{eff} = \varepsilon_{tag} (1-2\omega)^2$

(after passing trigger and offline cuts)

Channel	ε_{tag} (%)	w (%)	ε_{eff} (%)
$B^0 \to \pi^+\pi^-$	41.8±0.7	34.9±1.1	3.8±0.5
$B^0 \to K^+\pi^-$	43.2±1.4	33.3±2.1	4.8±1.0
$B^0 \to J/\psi\,(\mu\mu)K^0_S$	45.1±1.3	36.7±1.9	3.2±0.8
$B^0 \to J/\psi\,(\mu\mu)K^{*0}$	41.9±0.5	34.3±0.7	4.1±0.3
$B^0_s \to K^+K^-$	49.8±0.5	33.0±0.8	5.8±0.5
$B^0_s \to \pi^+K^-$	49.5±1.8	30.4±2.6	7.6±1.7
$B^0_s \to D^-_s\,\pi^+$	54.6±1.2	30.0±1.6	8.7±1.2
$B^0_s \to D^{\mp}_s K^{\pm}$	54.2±0.6	33.4±0.8	6.0±0.5
$B^0_s \to J/\psi\,(\mu\mu)\phi$	50.4±0.3	33.4±0.4	5.5±0.3

In the LHCb, measure ω using control channels with similar topology

Summary of principal physics channels

Decay channel	Factors (in %) forming ε_{tot} (in %) $\varepsilon_{det} \times \varepsilon_{rec/det} \times \varepsilon_{sel/rec} \times \varepsilon_{trg/sel} = \varepsilon_{tot}$					Assumed visible BR (in 10^{-6})	Annual signal yield	B/S ratio from incl. $b\bar{b}$ back.
	ε_{det}	$\varepsilon_{rec/det}$	$\varepsilon_{sel/rec}$	$\varepsilon_{trg/sel}$	ε_{tot}			
$B^0 \to \pi^+\pi^-$	12.2	91.6	18.3	33.6	0.688	4.8	26. k	< 0.7
$B^0 \to K^+\pi^-$	12.2	92.0	25.2	33.2	0.94	18.5	135. k	0.16 ± 0.04
$B^0_s \to \pi^+K^-$	12.0	92.1	13.5	36.7	0.548	4.8	5.3 k	< 1.3
$B^0_s \to K^+K^-$	12.0	92.5	28.6	31.1	0.988	18.5	37. k	0.31 ± 0.10
$B^0 \to \rho\pi$	6.0	65.5	2.0	36.0	0.028	20.	4.4 k	< 7.1
$B^0 \to D^{*-}\pi^+$	9.4	77.7	18.5	27.4	0.370	71.	206. k	< 0.3
$B^0 \to \overline{D}^0(K\pi)K^{*0}$	5.3	81.8	22.9	35.4	0.354	1.2	3.4 k	< 0.5
$B^0 \to D^0_{CP}(KK)K^{*0}$	5.2	81.4	29.4	31.2	0.390	0.19	0.59k	< 2.9
$B^0_s \to D^-_s\pi^+$	5.4	80.6	25.0	31.1	0.337	120.	80. k	0.32 ± 0.10
$B^0_s \to D^{\mp}_s K^{\pm}$	5.4	82.0	20.6	29.5	0.269	10.	5.4 k	< 1.0
$B^0 \to J/\psi(\mu\mu)K^0_S$	6.5	66.5	53.5	60.5	1.39	19.8	216. k	0.80 ± 0.10
$B^0 \to J/\psi(ee)K^0_S$	5.8	60.8	17.7	26.5	0.164	20.0	25.6 k	0.98 ± 0.21
$B^0 \to J/\psi(\mu\mu)K^{*0}$	7.2	82.7	35.1	69.9	1.462	59.	670. k	0.17 ± 0.03
$B^+ \to J/\psi(\mu\mu)K^+$	11.9	89.6	44.8	68.7	3.28	68.	1740. k	0.37 ± 0.02
$B^0_s \to J/\psi(\mu\mu)\phi$	7.6	82.5	41.6	64.0	1.672	31.	100. k	< 0.3
$B^0_s \to J/\psi(ee)\phi$	6.7	76.5	22.0	28.0	0.315	31.	20. k	0.7 ± 0.2
$B^0_s \to J/\psi(\mu\mu)\eta$	10.1	69.6	10.1	64.8	0.461	7.6	7.0 k	< 5.1
$B^0_s \to \eta_c\phi$	2.6	69.5	15.8	27.	0.078	21.	3.2 k	< 1.4
$B^0_s \to \phi\phi$	6.7	79.7	37.9	23.2	0.470	1.3	1.2 k	< 0.4
$B^0 \to \mu^+\mu^-K^{*0}$	7.2	82.4	16.1	73.5	0.704	0.8	4.4 k	< 2.0
$B^0 \to K^{*0}\gamma$	9.5	86.8	5.0	37.8	0.156	29.	35. k	< 0.7
$B^0_s \to \phi\gamma$	9.7	86.3	7.6	34.3	0.220	21.2	9.3 k	< 2.4
$B^+_c \to J/\psi(\mu\mu)\pi^+$	11.5	89.3	20.7	60.8	1.30	680.	14.0 k	< 0.8

Nominal year = 10^{12} bb pairs produced (10^7 s at L=2×10^{32} cm^{-2}s^{-1} with σ_{bb}=500μb)
Yields include factor 2 from CP-conjugated decays
Branching ratios from PDG or SM predictions

Performance after 1 LHCb year (2 fb^{-1})

	channel	yield	precision
γ	$B_s \to D_s K$	5.4k	$\sigma(\gamma) \approx 14^o$
	$B_d \to \pi\pi$, $B_s \to KK$	26k, 37k	$\sigma(\gamma) \approx 6^o$
	$B_d \to D^0 K^*$	0.5k	}
	$B_d \to \overline{D}^0 K^*$	3.4k	} $\sigma(\gamma) \approx 8^o$
	$B_d \to D_{CP} K^*$	0.6k	}
χ	$B_s \to J/\Psi\ \Phi$	120k	$\sigma(\chi) \approx 2^o$
$\lvert V_{td}/V_{ts} \rvert$	$B_s \to D_s \pi$	80k	Δm_s up to 68 ps^{-1}
rare decays	$B_d \to K^* \gamma$	35k	$\sigma(A_{CP}^{dir}) \approx 0.01$

+ systematics ! -> **talk by Guy Wilkinson**

Summary

- LHCb detector is optimized for precise measurement of CP violation and search for new phenomena
  - Exploit ~10^{12} b-hadrons / year with all b-species
    -> $B_{(s,c)}$-factory
- Complementary/competitive to (Super)-$B_{(d,u)}$-factories and Tevatron
- Detector construction is advancing well
  - To be ready for the first LHC collisions in 2007
- Physics potential can be fully exploited with the initial LHC luminosity

More on LHCb in Wednesday/Thursday talks:

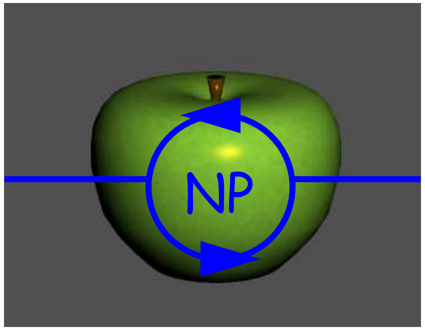
-> M.Needham "Status of the LHCb tracking system"
-> T.Bellunato "Status of LHCb RICH and HPD"
-> F.Teubert "LHCb trigger development"
-> G.Wilkinson "LHCb strategy to understand systematics"
-> P.Koppenburg "Reconstruction and analysis software environment of LHCb"

To conclude …

Historically, competitions on Beauty involve the famous apple …

… the Apple of Discord

… and in a few years …



BELLE

LHCb